Final Report

EFFECTS OF BARGE PASSAGE ON PHYSICAL, CHEMICAL, AND BIOLOGICAL CONDITIONS IN THE NAVIGATION REACH OF THE KASKASKIA RIVER

prepared by

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Upper Mississippi River Basin Commission

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INTRODUCTION

As part of efforts associated with consideration of a master plan for development of the Upper Mississippi River, an effort has been underway to identify and document impacts associated with navigational use of the Upper Mississippi system. In early 1981, a proposal was made to the Environmental Work Team to include a study of barge passage effects to be conducted on the Kaskaskia River. After review and revision of the proposal, funding was provided to study several barge passage events and monitor changes in the physical, chemical, and biological conditions of the river.

The navigation reach of the Kaskaskia River (Figure 1) is considered a part of the Upper Mississippi River system. The navigation reach was created by dredging a channel from the confluence of the Kaskaskia with the Mississippi River to Fayetteville, Illinois. For the most part, the existing river channel was incorporated in the channel, but the channel upstream from Channel Mile 20 required extensive modification creating a number of back waters (cut-off meanders). The channel meets specifications for a minimum depth of 9 ft with a top width of 300 ft and a bottom width of 275 ft. The channel was completed in 1973.

As part of ongoing research efforts at the University of Illinois, the Kaskaskia has been extensively studied since 1977. These studies have included physical, chemical, and biological analyses directed to the establishment of a sound baseline of data and identification of the effects of channel modification and navigation use on the channel ecosystem. Because extensive background data existed for the navigation reach, it was possible to design an experimental study which was supported by baseline data collected under a variety of seasonal and flow conditions. The fundamental study design included selection of a reach

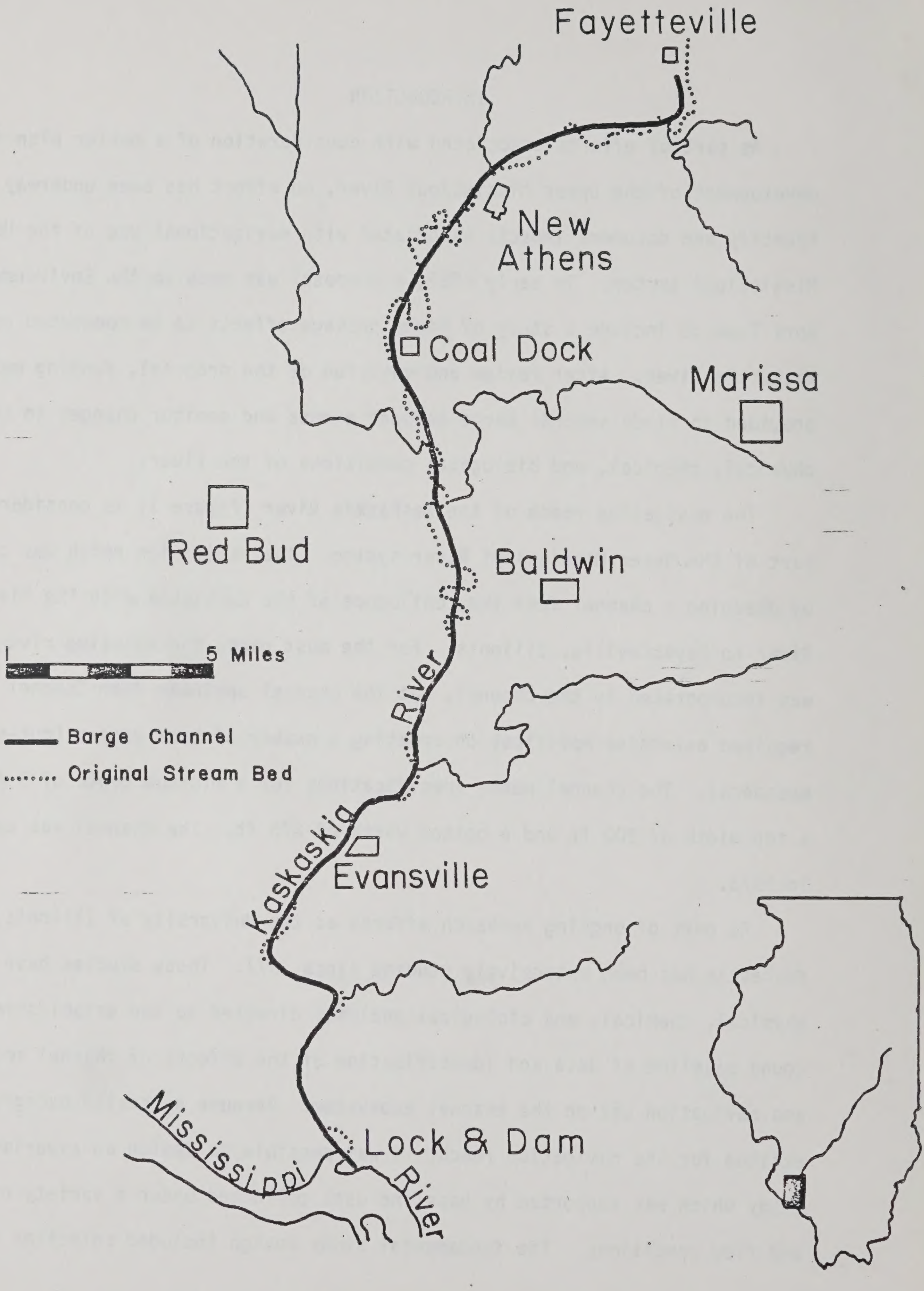

Fayetteville
New Athens
Coal Dock
Marissa
Red Bud
Baldwin
5 Miles
Barge Channel
Original Stream Bed
Kaskaskia River
Evansville
Lock & Dam
Mississippi River

Figure 1

of the river which was not subject to barge navigation and for which previous collections were available. A series of three transects, approximately 1/4 mile apart were established and sampling of physical, chemical, and biological parameters was scheduled before and after barge tows passed through the reach.

This report presents data collected from the study of barge passage during low flow and high flow. On March 16, 1981, a loaded four barge tow, driven by the 1200 hp towboat "Forward" passed through the experimental reach in an upstream direction followed by a downstream passage approximately one hour later. The flow at the time of passage was estimated at 700-800 cfs, low flow. Thus two passage events were monitored as a part of this study. On June 2, 1981, a second series of events was studied . The "Forward" passed through the study reach with an unloaded barge tow a total of 4 times. Two upstream and two downstream passages occured within 3 hours with a flow in excess of 4000 cfs (high flow) recorded. Where possible the effects of each passage event are individually reviewed.

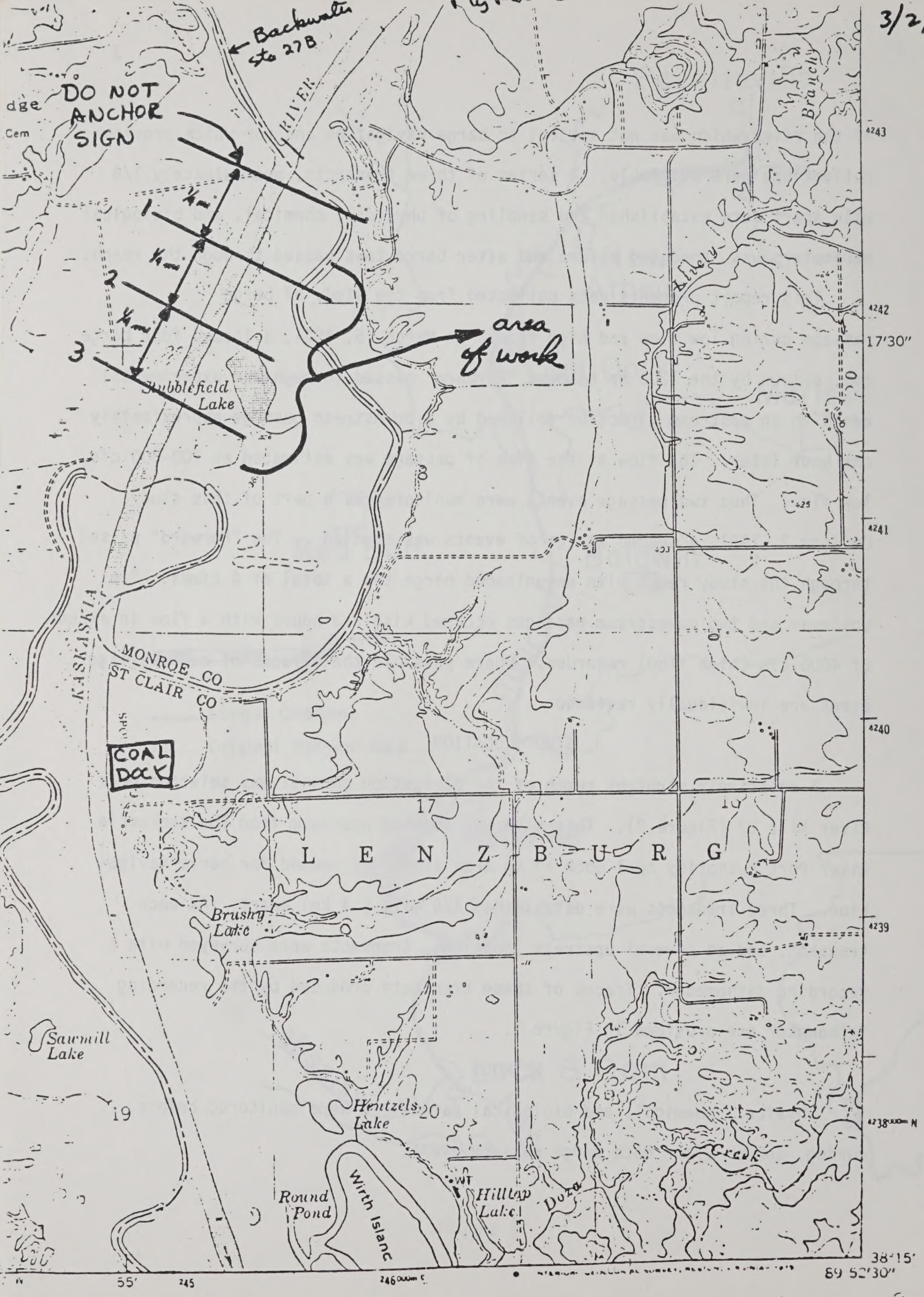
STUDY LOCATION

A relatively straight reach of the navigation channel was selected near River Mile 27 (Figure 2). This site was located upstream from the Kaskaskia River Port Authority coal dock in an area typically unused for barge navigation. Three transects were established 1/4 mile (.4 km) apart. At each transect, and at several upstream locations, transects were surveyed with a recording fathometer. Traces of these transects produced by the recording fathometer are provided in Figure 3.

METHODS

Physical, chemical, and biological parameters were monitored before, during, and/or after each barge passage event.

3/2/81


Backwater sta 27B
DO NOT ANCHOR SIGN
1
2
3
¼ mi
¼ mi
¼ mi
area of work
RIVER
Stubblefield Lake
KASKASKIA
MONROE CO
ST CLAIR CO
COAL DOCK
17
16
L E N Z B U R G
Brushy Lake
Sawmill Lake
Heutzels Lake
19
20
Round Pond
Wirth Island
Hilltop Lake
Doza Creek
Lively Branch
17'30"
38°15'
89°52'30"
55'
245
246000m E
4243
4242
4241
4240
4239
4238000m N
Cem
dge

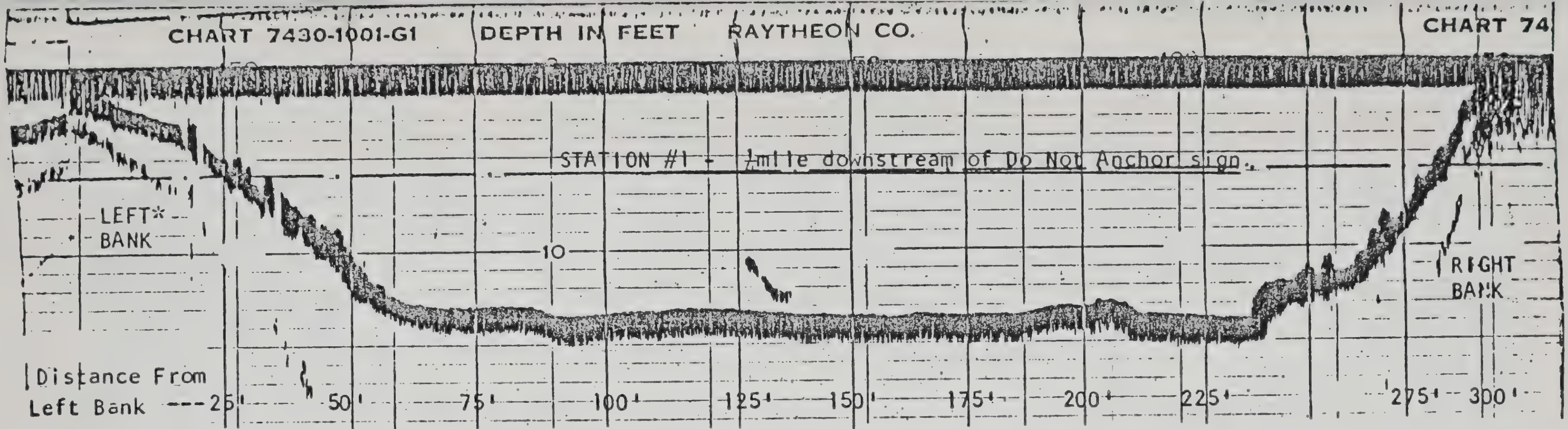


CHART 7430-1001-G1
DEPTH IN FEET
RAYTHEON CO.
CHART 74
STATION #1 - 1/4 mile downstream of Do Not Anchor sign.
10
LEFT* BANK
RIGHT BANK
Distance From Left Bank
25'
50'
75'
100'
125'
150'
175'
200'
225'
275'
300'

3/2/81

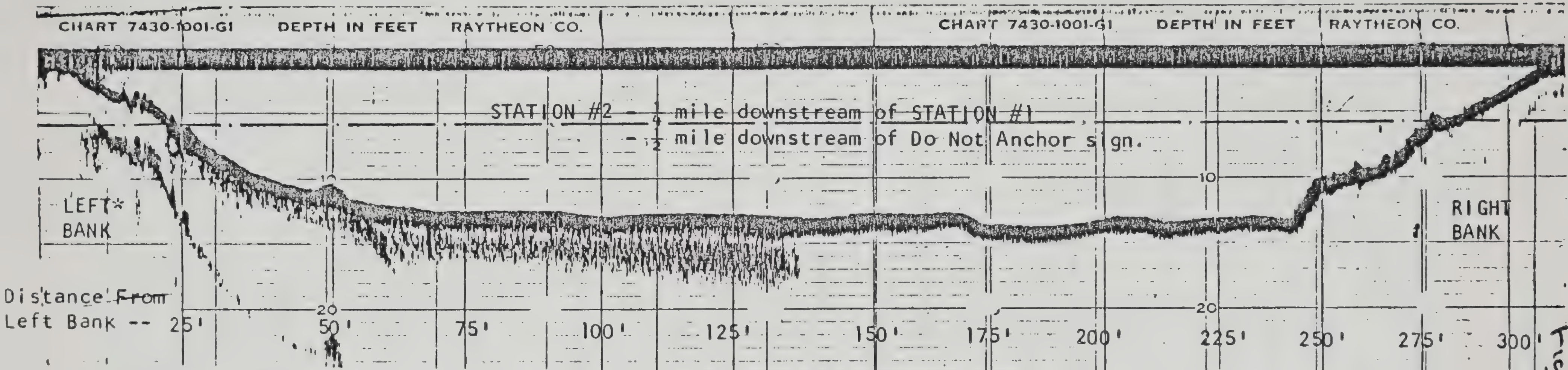
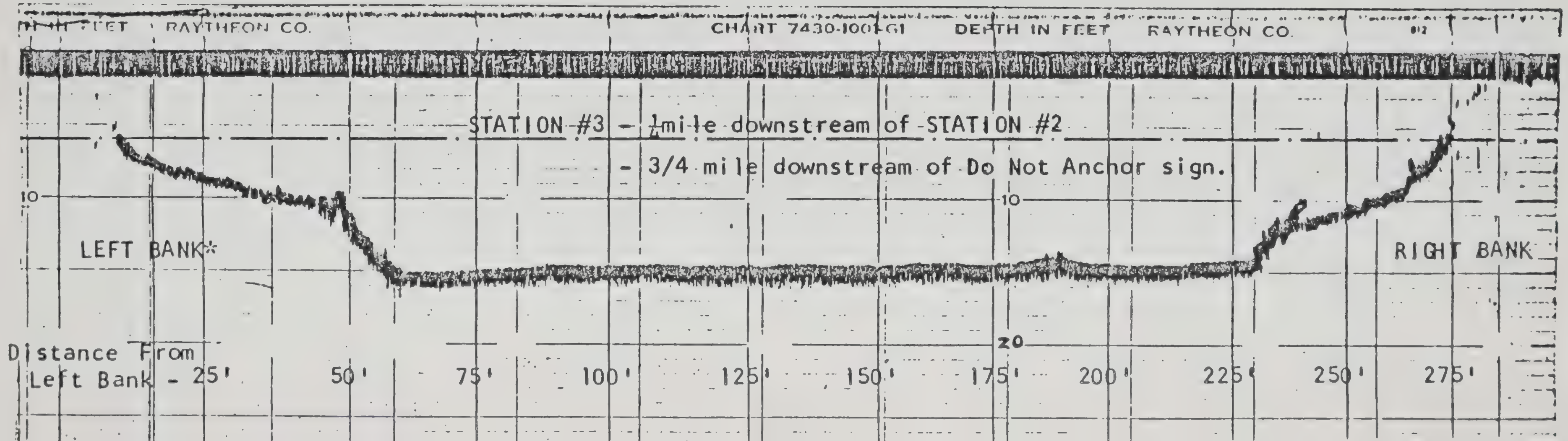


CHART 7430-1001-G1
DEPTH IN FEET
RAYTHEON CO.
STATION #2 - 1/4 mile downstream of STATION #1
- 1/2 mile downstream of Do Not Anchor sign.
10
20
LEFT* BANK
RIGHT BANK
Distance From Left Bank
25'
50'
75'
100'
125'
150'
175'
200'
225'
250'
275'
300'

Fig


RAYTHEON CO.
CHART 7430-1001-G1
DEPTH IN FEET
STATION #3 - 1/4 mile downstream of STATION #2
- 3/4 mile downstream of Do Not Anchor sign.
10
20
LEFT BANK*
RIGHT BANK
Distance From Left Bank
25'
50'
75'
100'
125'
150'
175'
200'
225'
250'
275'

Physical - Physical measurements included determination of temperature, sediment characteristics, and sediment movement. Temperature profiles were recorded using a temperature probe. Surface sediment characteristics were evaluated using a Ponar grab. A mimimum of five grab samples were made across each transect prior to barge passage. Following barge passage, samples were collected within 24 hours of the passage event(s). Additional samples were collected 2 to 3 weeks following passage. Samples were returned to the labortory and size class analysis performed. Standard ASTM Procedures were adapted from ASTM D422-61T with four size classes determined: Gravel (sieve #10 2 mm diameter), Coarse Sand (sieve #30 0.06 mm diameter), Medium Sand (sieve #60 0.35 mm diameter), Fine Sand (sieve #200 0.074 mm diameter) and Silt (not retained on a #200 sieve). Sediment movement was monitored using sediment traps. Sediment traps followed designs proposed by Kimnel, et al. (1977). Traps were placed in mid-channel and on the right bank at transect #2. For the March sample and at left bank, mid-channel and right bank for the June sample. Traps were left in place for approximately 24 hours. Samples were retrieved for periods prior to barge passage, during barge passage, and following barge passage. Secchi disk (transparency) measurements were made during the June study.

March samples were analyzed for size distribution using the "Pipette Method" which involves suspending the sample in one liter of water and removing 20 ml subsamples at discrete time intervals based on the expected settling rate of the particles. Each subsample is then run through a pre-weighed filter and dried so that the total mass of each size class can be ascertained. Although this method worked well for the March samples, with total mass generally less than 3g, it was not appropriate for the June samples. The June samples occurred during a period of higher flow which resulted in greater

background levels of sedimentation. ASTM Method D422 recommends using hydrometry for analysis of sample sizes of 50g or greater. Hydrometry analysis is also based on the settling rate of different size classes but measures the decrease in density of the suspension as particles settle out over an 8 hour period. As with the Pipette Method, this allows one to calculate the size distribution of particles ranging from coarse silt through clay.

Chemical - Chemical analyses included determination of dissolved oxygen immediately before and immediately following barge passage. In addition, total suspended solids levels were determined. Samples for dissolved oxygen, suspended solids, were collected from the surface, 1.5 m, 2.5 m and/or 3.5m, from either mid-channel or near the bank stations.

Biological - Biological sampling included analysis of macrobenthic bottom fauna drift. Chlorophyl analysis was performed on March samples. Bottom fauna was sampled using a Ponar grab. Two 9" x 9" grabs were composited for each sample, five samples were collected across each transect. Samples were field washed through a #30 sieve preserved and returned to the laboratory for analysis. Drift samples were collected as a part of all studies with two 1 ft diameter bongo nets attached to each side of the boat producing four replicate samples. Because current velocity was extremely low during the March study, a 5 minute sample was collected by maintaining a constant speed with the boat suspended nets. Drift samples were preserved and returned to the laboratory for analysis. Emphasis was placed on the occurence of macrobenthic organisms in the samples. Chlorophyll samples were collected in conjunction with DO and suspended solids samples at the surface 1.0m, 2.5 m, and/or 3.5m.

A Shannon-Wiener species diversity index (H') was calculated for each ponar grab collection using the formula:

$$H' = -\varepsilon P_i \ln p_i$$

where, P_i is the proportion of taxon i in the community. The calculated H' indices, total numbers of individuals, and total number of taxa were compared on the basis of sampling location and time using a one-way analysis of variance (ANOVA) according to Nie et al. (1975). The Duncan's multiple range *a posteriori* test was employed when significant differences were detected in the initial ANOVA comparisons. Throughout the benthic and drift analyses, a critical α of 0.05 was employed. The same methods were employed for testing for differences in the number of individuals collected from the drift. The actual comparisons are described throughout the text.

Because the experimental conditions differed significantly between the March and June studies, each study will be discussed separately. The March event was characterized by low flows and extremely low current velocities. The passage of a loaded tow through the experimental reach was coordinated to provide samples associated with each passage event. The June studies were characterized by high flow and high current velocities. Based on analysis of March sampling, an increased emphasis was placed on drift studies rather than further ponar grab analysis. A total of four passages occurred through the reach. Sampling was designed to observe the cumulative effect of all passage events; thus, sampling occurred before and after the passage cycle.

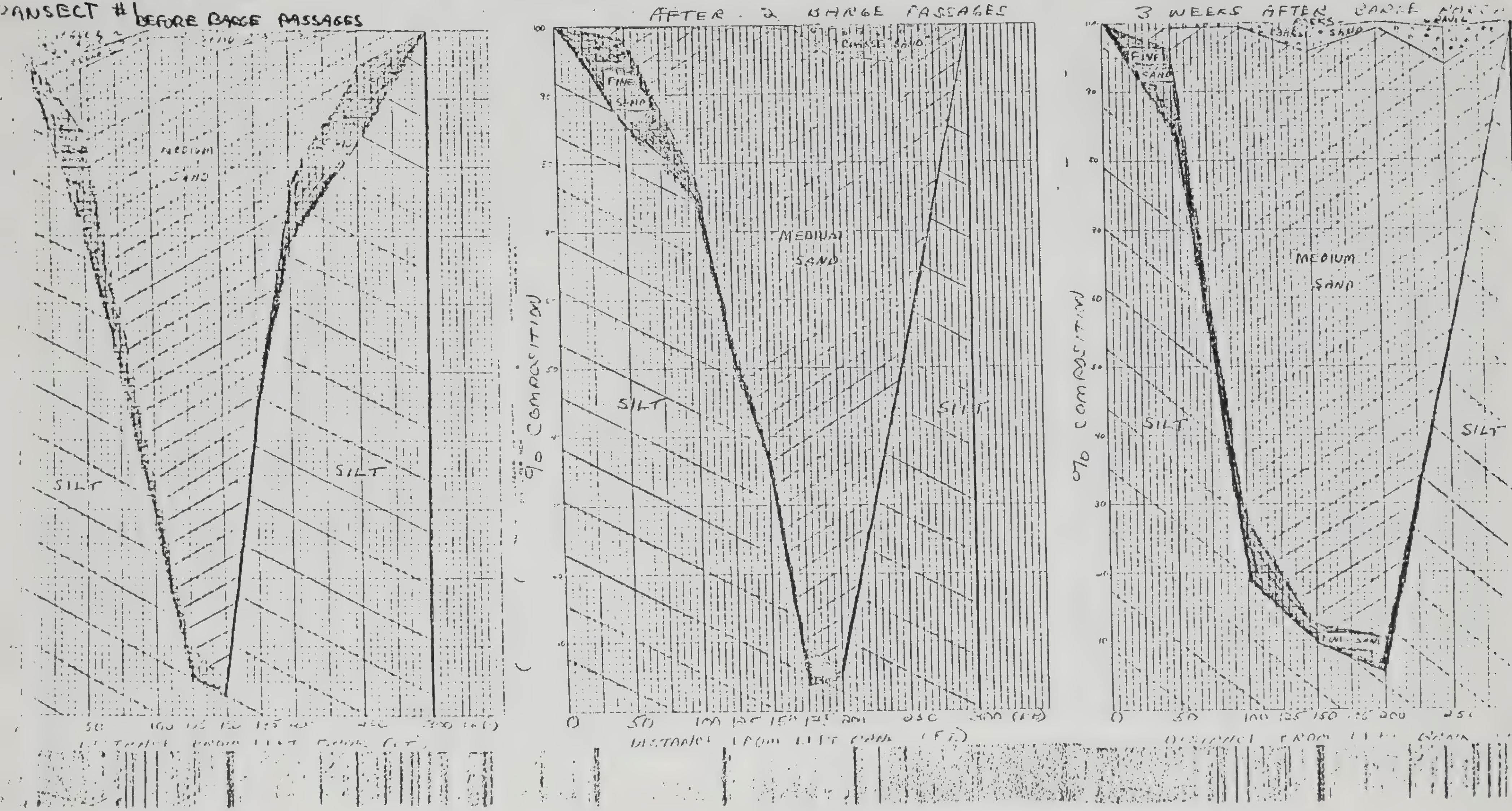
RESULTS AND DISCUSSION

Low Flow Studies

Physical Results. The Kaskaskia navigation channel was experiencing low flow conditions at the time of the barge passage study. Current velocity was undetectable using a Price/Gurley flow meter suspended in the channel.

The results of size class analysis of surface sediments is contained in Figures 4-6. The first comparison can be made between size class analyses of

Figure 3



ANSECT #1 BEFORE BARGE PASSAGES

AFTER 2 BARGE PASSAGES

3 WEEKS AFTER BARGE

Figure 4

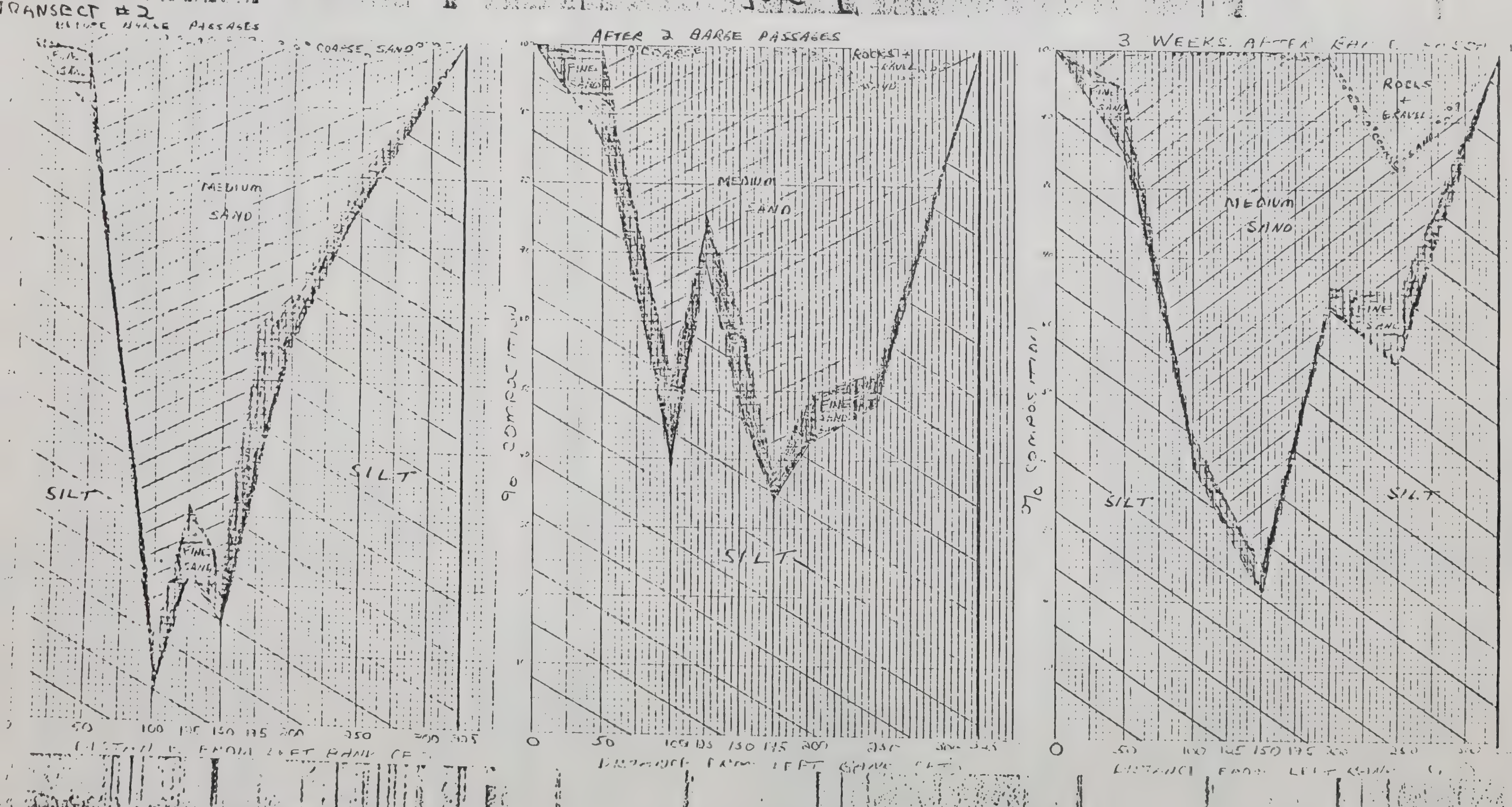
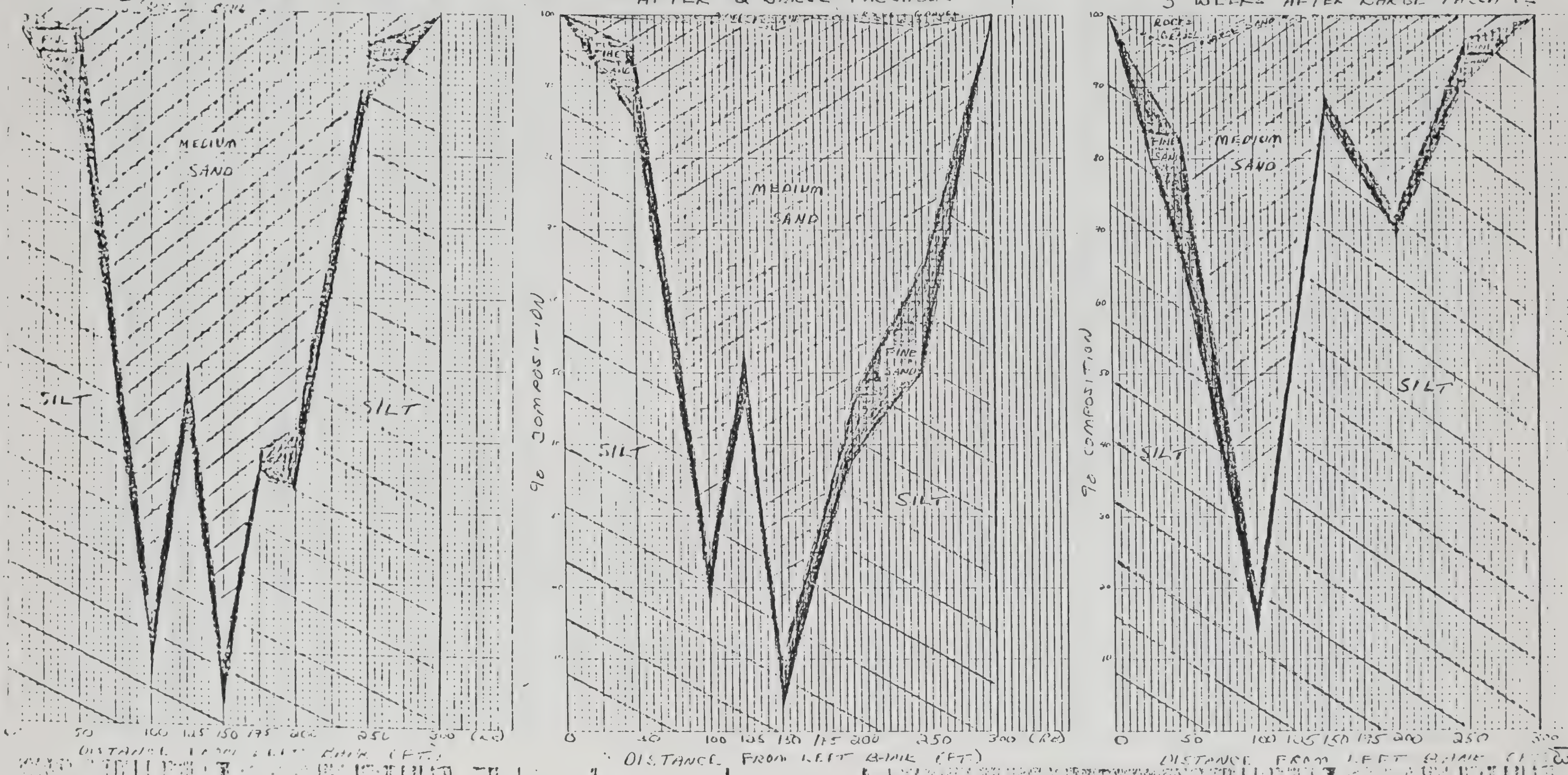

TRANSECT #2
BEFORE BARGE PASSAGES
COARSE SAND
MEDIUM SAND
FINE SAND
SILT
SILT
50
100
125
150
175
200
250
300
325
DISTANCE FROM LEFT BANK (FT)
AFTER 2 BARGE PASSAGES
COARSE
FINE SAND
ROCKS + GRAVEL
MEDIUM SAND
FINE SAND
SILT
% COMPOSITION
0
50
100
125
150
175
200
250
300
325
DISTANCE FROM LEFT BANK (FT)
3 WEEKS AFTER
FINE SAND
ROCKS + GRAVEL
COARSE SAND
MEDIUM SAND
FINE SAND
SILT
SILT
% COMPOSITION
0
50
100
125
150
175
200
250
300
DISTANCE FROM LEFT BANK

Figure 5

RANSECT #3


BEFORE BARGE PASSAGES — AFTER 2 BARGE PASSAGES — 3 WEEKS AFTER BARGE PASSAGES

samples taken before and after barge passage. The most striking change occurred at transect #2 where following barge passage a greater silt fraction occurred in mid-channel samples. The change in sediment characteristics at other transects was not as dramatic and largely limited to slight increases in coarse sand and gravel fractions. The coarse bottom materials are typically associated with right bank locations following barge passage (transects #1 and #2) while at transect #1 the coarse fraction was the greatest on the left bank prior to barge passage. It appears that barge passage may influence the relative percentage of coarse materials from this data. If additional analysis of substrate characteristics is made, other mechanisms of substrate size characteristics maintenance are indicated. Evaluating the results of size class analysis performed on samples collected three weeks after barge passage indicates major changes from previous samples. Coarse materials can be noted near the right bank of both transects #1 and #2 and major changes in location and percentage of silt fractions can be noted at all transects.

The characteristics of sediments will be controlled by the physical conditions in the stream channel. As the capacity for sediment movement and transport is generally related to velocity (i.e., the sixth power law) the results of size class analysis are not surprising. Since in any channel a region of somewhat greater velocity will generally be related to the thalweg (area of deepest flow), this data can be used to identify the probable location of the thalweg. Since the channel is very wide, we may also expect the thalweg, or at least areas of maximum velocity to shift similar to the meander patterns present in all rivers. The variability in the sediment characteristics can be accounted for by this mechanism. The data also points to direct effects of barge passage on sediment size characteristics. Barge passage will create turbulence (and a velocity gradient) which can move sediment particles. In the experimental reach, the silt fraction in the mid-channel areas was altered following barge passage. The dominance of silt sized particles along both banks is representative of previous samples and is indicative of decreased current velocities typical of channel margins.

To expand on the movement of sediment associated with barge passage, the results of sediment trap data can be analyzed. Figure 7 provides the results of sediment trap collections before, during, and after passage events. Figure 7 contains the results of analyses of all size fractions from right bank and main channel traps. The sedimentation rate in the experimental reach is typically highest for fine and medium silt fractions. Right bank and main channel values are generally similar with the exception of the greater rate of sand accumulation in the main channel. Major increases in the rate of sediment accumulation occurred during the period of barge passage. The finer sized particles tended to accumulate along the banks (as indicated by the right bank samples) while the sand fraction showed the largest increase in the main channel. Following barge passage both medium and coarse silt fractions showed accumulation rates greater than prepassage levels.

The results of sediment trap analysis confirm several hypotheses made about barge passage effects on substrate conditions which can only be indirectly determined from the previous sediment size class analysis. First, the typical accumulation rates of different size fractions differs from the banks to mid-channel. Typically, smaller size fractions accumulate along the banks where velocities are lower. The higher rates of sand accumulation in the main channel is typical of areas where the competence for sediment movement (e.g., increased velocity) is greater. The effects of barge passage included increasing the rates of silt accumulation in the bank areas while

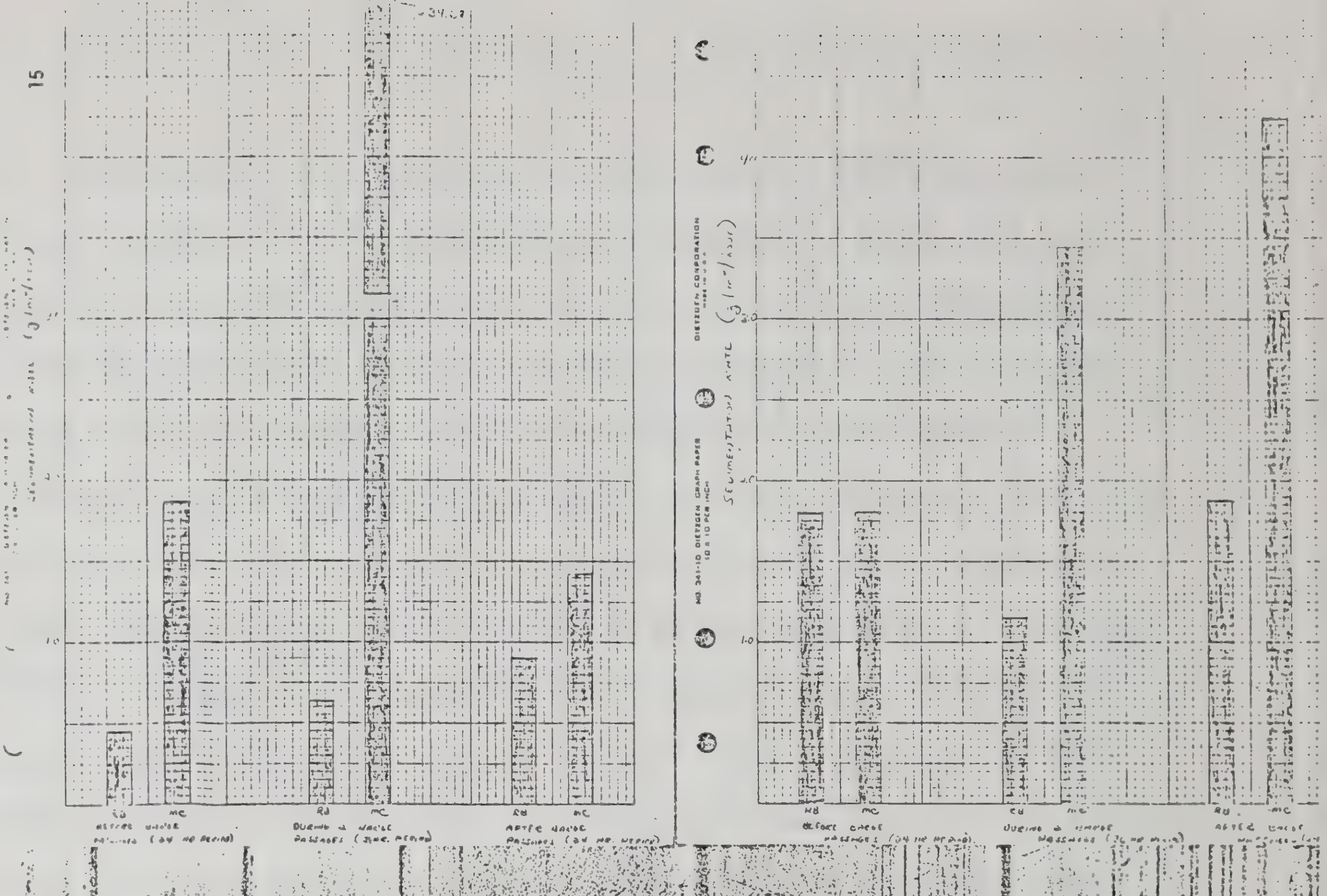


Figure 6

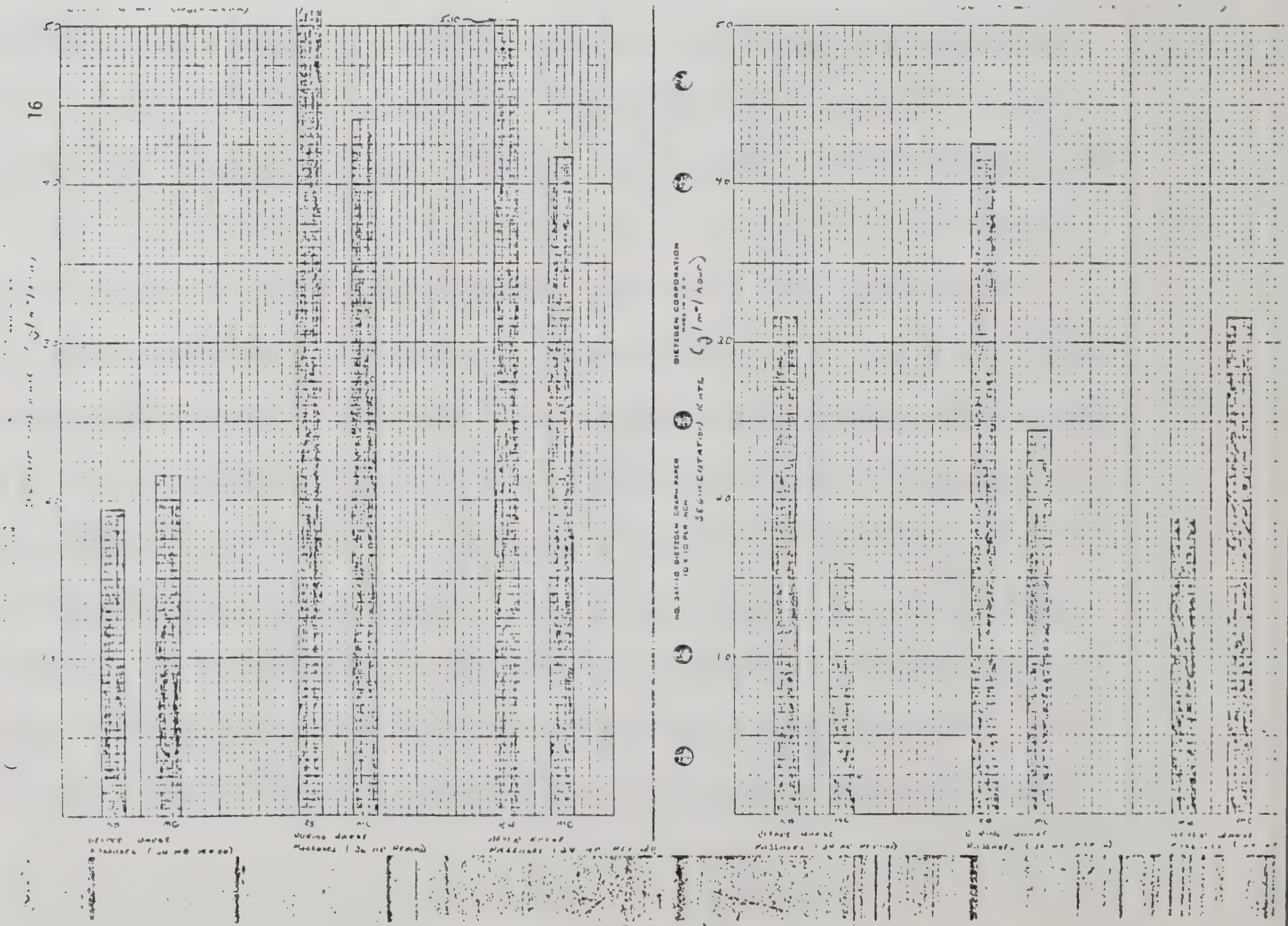


Figure 7

increasing the rate of sand accumulation in mid-channel. The proposed mechanism producing these results is turbulence produced by tow propulsion. The results of sediment size fraction accumulation rate analysis following barge passage also follow expected results. The fine silt fraction will tend to stay in suspension for a greater time than either the medium or coarse silt fractions. The occurrence of higher rates of deposition for the medium and coarse fractions then would follow an expected decay curve for different sized particles. Post passage sand accumulation rates were quite similar to prepassage levels.

Chemical Results. The results of chemical analyses further identify the effects of barge passage on the navigation reach. Dissolved oxygen values from the mid-channel are contained in Table 1 prior to and following barge passage. As in previous studies (Herricks and Gantzer, 1980), there is a decrease in integrated dissolved oxygen values following barge passage with a corresponding increase in integrated values during the following 30 minutes. The proposed mechanism which explains these results includes turbulent mixing of the water column with a corresponding loss of dissolved oxygen from slightly supersaturated surface waters causing a decrease in integrated column values.

Although chlorophyll is usually considered in biological discussions, the discussion of chlorophyll results with water quality analysis results amplifies trends observed using similar sampling techniques. Chlorphyll analyses corresponding to the dissolved oxygen sampling schedule indicate that although slightly higher concentrations occurred near the bottom in the mid-channel before barge passage, following passage chlorophyll concentrations were similar (Table 2). A slight increase in chlorophyll concentrations occurred at the bottom 30 minutes following passage

Table 1

Dissolved Oxygen (mg/l) at Mid-Channel Station with Barge Tow Traveling Upstream

d.	45BB1	7AB1	17AB1	32AB1
surf	15.93	13.74	14.81	13.96
1 m	13.94	12.77	12.93	14.07
2 m	13.99	12.72	13.64	13.13
3.5 m	15.06	13.64	13.03	13.60
Int. (g/m^2)	50.69	45.77	47.16	47.66

Temperature Profile at Mid-Channel Before Barge Passage

Depth	°C
0	8.0
1	7.7
2	7.2
3	6.8
4	6.7

Table 2

Chlorophyll Analysis for the March Study

Depth	45BB1	7AB1	17AB1	32AB1
surf	65.2	67.8	59.6	53.1
1 m	54.8			
2 m	89.2	66.7	65.4	88.2
3.5 m	111.0			

Depth	20BB1-S	4BB2-S	5AB2-S	15AB2-S	33AB2-S
surf		83.7	86.6	82.5	57.0
2.5 m	(2.0)79.3	78.8	84.5	83.8	89.5

probably due to settling of algae. On the right bank little change was noted in chlorophyll concentrations until 33 minutes after passage of the second barge. The increase in chlorophyll concentration occurred at the bottom of the water column. The potential mechanism which will explain these results is supported by a review of the suspended solids data.

The results of suspended solids analysis are contained in Table 3. Suspended solids analyses included samples from several depths collected before from the mid-channel and from the right bank after the barge passage events. Integrated column suspended solids values were calculated from the results. The integrated value increased by a factor of approximately 2.3 following barge passage. The integrated column values then declined to levels approximately 25% greater than prepassage levels in 32 minutes. The dissolved solids concentrations along the right bank were monitored following the downstream passage. Integrated column suspended solids values showed a lower overall maximum increase (increasing approximately 70%) which was delayed when compared to mid-channel values (15 minutes for the right bank vs 7 minutes for the mid-channel).

The results of suspended solids analysis provide additional insight into the movement of sediments in the experimental reach due to barge passage. The immediate effect of the barge on the main channel is the increase in suspended solids due to the suspension of bottom materials. The slightly lower suspended solids concentrations in the samples from 2.5 m and 3.5 m depth can be related to more rapid settling of larger particles which are not mixed throughout the water column. Elevated values at the surface are likely due to smaller particles which are mixed throughout the column and settle less rapidly. Within 17 minutes water column values become more uniform as the integrated values decrease. Along the banks the major

Table 3

Suspended Solids Data from March Study

Upstream passage, mid-channel sampling 4 meters deep

mg/l

Depth	45BB1	7AB1	17AB1	32AB1
surf	71	367	177	161
1 m	91	362	155	146
2 m	86	244	174	158
3.5 m	272	241	165	166
Int. (g/m^2)	438	1031	585	548

Downstream passage, side station 3 meters deep

	Upstream	Downstream			
Depth	20BB1-S	4BB2-S	5AB2-S	15AB2-S	32AB2-S
surf	104	134	118	124	113
1 m	135	125	158	253	203
2.5 m	160	179	250	267	176
Int. (g/m^2)	341	358	444	579	442

Note: Integration down to bottom Van Doren's depth, 20BB1-S and 4BB2-S are 1 hour and 9 minutes apart and one barge passage during this time.

increase in suspended solids occur near the bottom with an increase which is slower than that observed in the mid-channel. By and large, surface suspended solids values along the bank increase very little. A proposed mechanism which would fit these results is a current created by the barge which is subsurface (at the approximate level of the props). This subsurface current forces the circulation of suspended materials out from the main channel along the bottom. Large particles rapidly settle out of the water column (as indicated in the sediment trap results) and only the smaller sized particles move to the bank areas where their slow settling produces a delayed increase in suspended solids levels. These results further illuminate possible mechanisms causing the physical alternations previously related to barge passage.

In summary, the effects of barge passage on chemical conditions is significant. Integrated dissolved oxygen values decrease and suspended solids concentrations are elevated. Chlorophyll values indicate mixing in the main channel areas. The effects on the banks due to barge passage are not as dramatic and somewhat delayed (occurring approximately 10 minutes following passage). Different mechanisms appear to operate in the two channel regions.

Biological Results. Biological sampling included analysis of drift before and after barge passage as well as Ponar grab sampling of benthic macroinvertebrates before and after each passage event to determine possible effects on the benthic community.

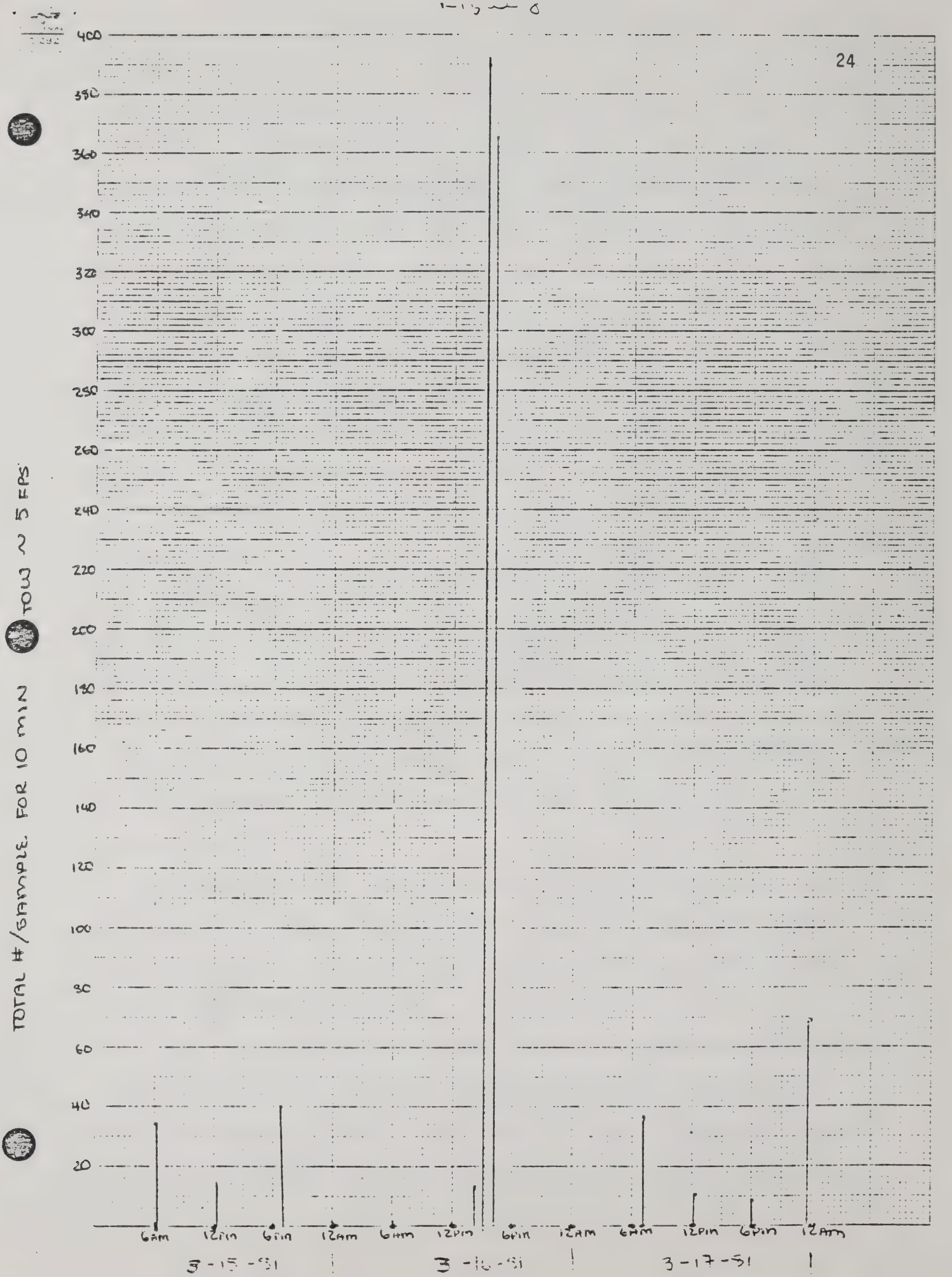
Table 4 provides a summary of the numbers of various orders of invertebrates collected before and after barge passage in drift samples. The drift was dominated by mayflies and midges with significant numbers of water mites and oligochaetes also occurring in the samples. Figure 8 provides a

Table 4

Total Number of Organisms per Taxonomic Grouping Collected
in a 10 Minute Tow, Average Speed 5 FPS.
(average value per net)

	Time	I.D.	Ephemeroptera	Chironomidae	Other Diptera	Oligochaeta	Hydrachinidae	Mollusca	Odonata	Coleoptera	Amphipoda	Hemiptera	Misc.	Total
3-15-81	6:11	#1	2	20.5	2	7.5	0.5				1	0.5		34
	12:24	#2		7.5	3.5		1			1				13
	19:26	#3	13.5	18.5	4.5	2.5					0.5			39.5
3-16-81	14:50	#4	4	5	3	0.5								12.5
	15:45	#5	59	225.5	9	8.5	81.5	4.5					2	389.5
	15:55	#6	70	205.5	11	6	64.5	4	1.5			0.5	1.5	364.5
3-17-81	7:00	#7	5.5	7.5	4.5	4.5	13.5						0.5	36.5
	12:30	#8	0.5	1.5	1	5.5	2							10.5
	18:00	#9		2	1.5	1.5	3.5							8.5
	23:30	#10	13.5	34.5	20.5		0.5						0.5	69

NOTE: 1 sample = 2 nets


TOTAL #/SAMPLE FOR 10 MIN TOW ~ 5 FPS
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
6AM
12PM
6PM
12AM
6AM
12PM
6PM
12AM
6AM
12PM
6PM
12AM
3-15-81
3-16-81
3-17-81

numerical comparison of the change in magnitude of drift related to barge passage. Approximately a 10-fold increase in drift was observed following barge passage. Table 5 lists the dominant species associated with the bank areas (including rip-rap) and dominant bottom genera. Table 6 lists the percentage of total individuals in each drift sample which is made up of fauna typical of bottom and bank regions of the channel. Prior to barge passage, bottom dwelling organisms dominated the drift. It is apparent from these results that the passage of a barge over the bottom and the suspension of sediment materials also causes a significant suspension of aquatic organisms. Immediately following barge passage burrowing mayflies and midge species typical of bottom areas occurred in the drift in high numbers. Oligochaetes and water mites dominated later drift samples although some periodicity of both burrowing mayfly and midge drift was apparent.

Ponar grab samples collected on March 15-17 and April 4, 1981 were analyzed to determine if: 1) differences in benthic communities could be attributed to channel location, 2) differences could be identified between channel locations for each sampling date, 3) differences occurred within channel locations for the three dates sampled, and 4) any of the observed differences were attributable to barge traffic. In the analysis of the samples from three transects (channel replicates) and five channel locations (left bank through right bank looking downstream) along each transect was analyzed independently. The ANOVA and Duncan's multiple range a posteriori test were applied using total numbers of taxa, total numbers of individuals, and calculated diversity indices (H').

Differences were found in the total numbers of taxa and individuals and in the calculated H' diversity indices during the study (Table 7). Table 7 indicates that from March 15 through April 4, 1981 the structure of the

Table 5

Genera Typical of Side or Channel Margin Habitats

POLYPEDILUM
GLYPTOTENDEPES
PSEUDOCHIRONOMUS
CRYPTOCHIRONOMUS
CRICOTOPUS
CAENIS
STENACRON

Genera Typical of Main Channel Bottom Habitats

PROCLADIUS
STICTOCHIRONOMUS
COELOTANYPUS
CHIRONOMUS
HEXAGENIA

Table 6

Percentage of Total Drift Sample with Fauna Typical of Bottom and Side Habitats

Date	Time	ID	Side	Bottom	Misc
3-15-81	6:11	#1	58.6	5.04	36.36
	12.24	#2	46.2	0	53.8
	19:26	#3	21.0	54.9	24.1
3-16-81	14:50	#4	35.4	26.7	37.9
	15:45	#5	4.5	63.0	32.5
	15:55	#6	5.5	64.3	30.2
3-17-81	7:00	#7	5.3	21.7	73.0
	12:30	#8	6.25	6.25	87.5
	18:00	#9	0	15.0	85.0
	23.30	#10	16.5	53.2	30.3

Table 7

Results of oneway ANOVA and a posteriori tests on biological parameters obtained from ponar grab samples for the March 15-April 4, 1981 sampling period with respect to channel location.

Parameter	df.	F	Probability	Duncan's MRT
No. of taxa	48	10.11	<0.001	3 4 2 5 1
No. of individuals	48	3.63	<0.05	4 3 2 5 1
H' diversity	48	11.38	<0.001	3 4 2 5 1

Kaskaskia benthic community was different based on sample location across each transect. Subsequent a posteriori comparisons (Table 7) indicated that the left and right bank stations (i.e. 1 and 5) generally had a higher species richness and diversity, while the mid-stream (i.e. 2, 3, and 4) had significantly fewer numbers of taxa and individuals and a lower diversity. These results are consistent with previous studies (e.g. Heinzen 1980).

Significant differences associated with channel location were found in the total numbers of individuals collected on March 15 and March 17, and in the calculated H' indices on March 17 (Table 8). In all cases where significant differences were detected, the left bank (looking downstream) values were significantly greater than the other sampling locations (Table 8). No significant differences due to channel location were found in any of the community parameters from the April 4, 1981 collections. The similarities in the structure of the benthic communities on March 15, 1981, prior to barge passage, and March 17, 1981, following 3 barge passages, suggest that barge traffic was having no discernible effects on the structure of the benthic macroinvertebrate communities (Table 8), although natural differences presumably did exist between main channel and lateral stations (Tables 7 and 8).

Due to the variability in the structure of the benthic communities from bank to bank (Tables 7 and 8) it would be difficult, if not impossible, to determine the effects of barge traffic on the benthic communities by comparing samples taken across a transect. Therefore, the data from each of the five channel locations were compared through time (March 15 vs 17 vs April 4 collections) to determine the effects of barge traffic on the macroinvertebrate communities within cells defined by sampling location across the river. No significant differences were found in any of the

Table 8

Results of oneway ANOVA's and *a posteriori* tests on biological parameters obtained from ponar grab samples for each sampling day with respect to channel location (N.S.=not significant; N.A.=not applicable)

Parameter	df	F	Probability	Duncan's MRT
MARCH 15:				
No. of taxa	12	3.82	N.S.	N.A.
No. individuals	12	3.96	<0.05	4 3 2 5 1
H' diversity	12	1.96	N.S.	N.A.
MARCH 17:				
No taxa	14	3.18	N.S.	N.A.
No. individuals	14	6.34	<0.01	4 3 5 2 1
H' diversity	14	3.88	<0.05	3 2 4 5 1
APRIL 4:				
No taxa	15	2.91	N.S.	N.A.
No. individuals	15	0.33	N.S.	N.A.
H' diversity	15	3.04	N.S.	N.A.

benthic community parameters examined at a channel location before or after barge passage (Table 9) indicating that the passage of a barge during the March 16 and 17, 1981 sampling periods had no detectable effect on the structure of the benthic communities.

These results indicate that: 1) differences do exist in the structure of benthic communities when examined along a transect, both within a single day and throughout the study, 2) no differences exist in the structure of benthic communities between transects and, 3) there is no indication of a significant effect of the barge passage on the number of taxa, individuals or calculated diversity of Kaskaskia benthic communities during low flow periods.

High Flow Studies

As a preface to the review of the results of high flow studies several comments should be made concerning the differences which existed between the two studies. The most significant difference was flow condition (and associated current velocity). In addition, the characteristics of the barge tow differed between the two studies. The barge tow for the June, high flow, studies consisted of four unloaded barges driven by the "Forward". In calculation made for previous studies, a loaded tow will displace approximately 16% of the channel volume in the Kaskaskia navigation channel (Herricks and Gantzer, 1980). The unloaded barges displace approximately 17% of that amount and are likely to have a correspondingly lower impact due to water displacement. It can be expected that lower resistance will result in decreased propwash effects as well. Thus high current velocities and a different barge configuration provided a different set of experimental conditions.

Table 9

Results of oneway ANOVA's and *a posteriori* tests on biological parameters obtained from ponar grab samples for each sampling station with respect to sampling periods. (N.S.=not significant; N.A.=not applicable)

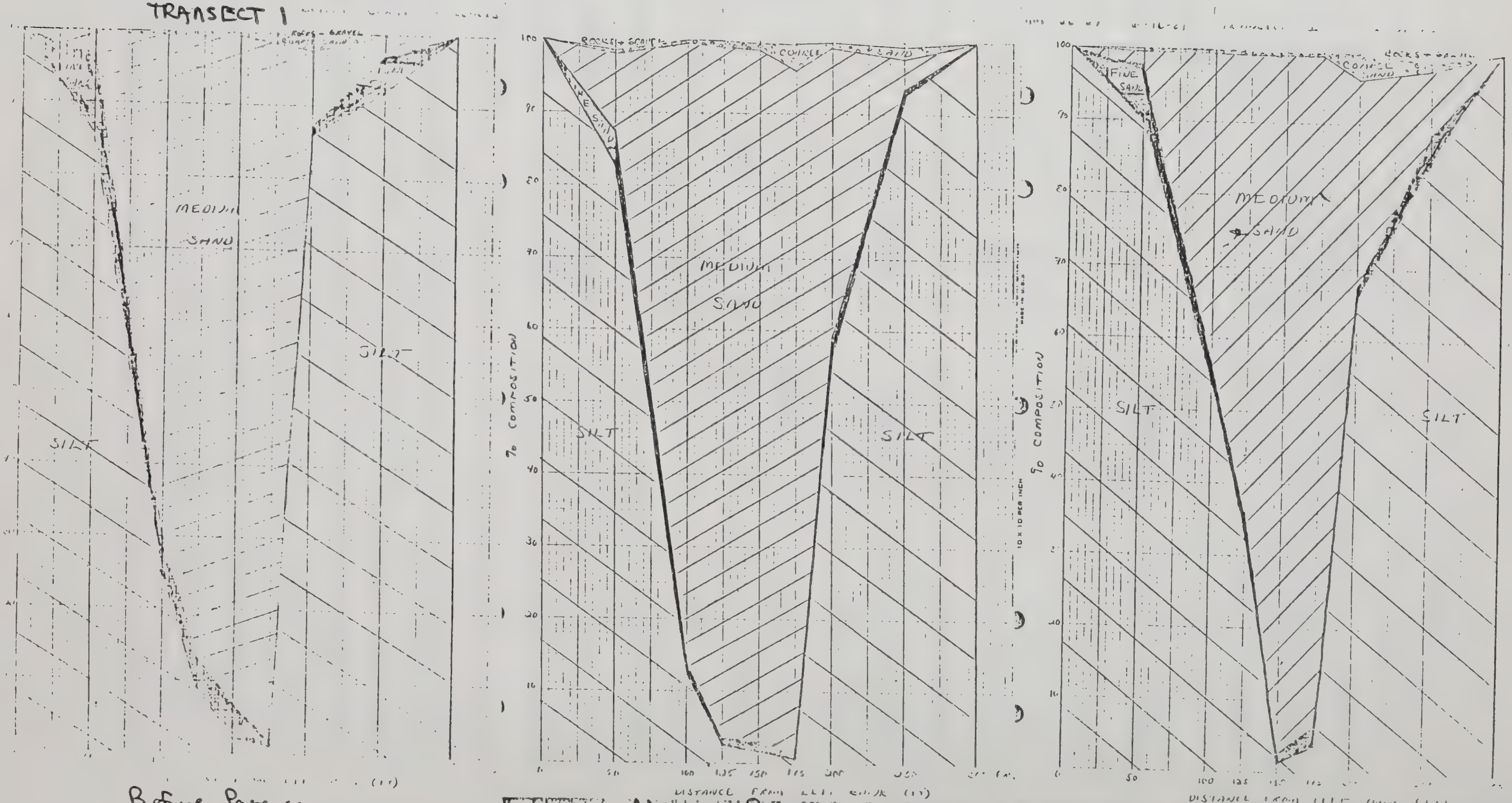
Parameter	df	F	Probability	Duncan's MRT
STATION 1:				
No. of taxa	9	2.068	N.S.	N.A.
No. individuals	9	3.004	N.S.	N.A.
H' diversity	9	0.433	N.S.	N.A.
STATION 2:				
No. of taxa	9	0.259	N.S.	N.A.
No. individuals	9	3.691	N.S.	N.A.
H' diversity	9	0.274	N.S.	N.A.
STATION 3:				
No. of taxa	9	0.107	N.S.	N.A.
No. individuals	9	0.654	N.S.	N.A.
H' diversity	9	0.185	N.S.	N.A.
STATION 4:				
No. of taxa	9	0.369	N.S.	N.A.
No. individuals	9	0.605	N.S.	N.A.
H' diversity	9	0.543	N.S.	N.A.
STATION 5:				
No. of taxa	8	1.545	N.S.	N.A.
No. individuals	8	1.506	N.S.	N.A.
H' diversity	8	0.045	N.S.	N.A.

Physical Results. Current velocities during the study of barge passage events ranged from 0.69 to 1.95 fps in the water column (with a calculated average of 1.46 fps) at the lateral stations. Mid-channel location velocities ranged from 0.48 to 2.34 fps through the column, with a calculated average of 1.98 fps.

Sediment characteristics were monitored observing change in size class analysis of surface sediments, Figures 9, 10, and 11. The results from after barge passage events indicate some change in sediment characteristics. In general the percentage of coarser materials increased. There were major differences between transects. Two weeks following barge passage, sediment characteristics were also variable, generally demonstrating an increase in smaller size classes along the banks. These results are consistent with the March, low flow, study.

The results of sediment trap analysis are contained in Figure 12. Sediment in the size range of clay and silt tended to accumulate at a somewhat greater rate during barge passages with differences noted between lateral and main channel locations. This result was not noted for sand size particles, where greater accumulation in the mid-channel occurred both before and after barge passage but not during the passage event. For the most part these results are consistent with the results of the low flow study. Fine sediment particles tended to accumulate along the banks during the barge passage events while mid-channel locations did not show as great an increase. The major inconsistency occurred at the main channel location for sand. Both before and after barge passage main channel sand sedimentation rates were much greater than observed during barge passage. This result can be due to either sampling and analysis errors or the result of high flow and barge passage. In the analysis procedure using hydrometry, a small

Figure 9

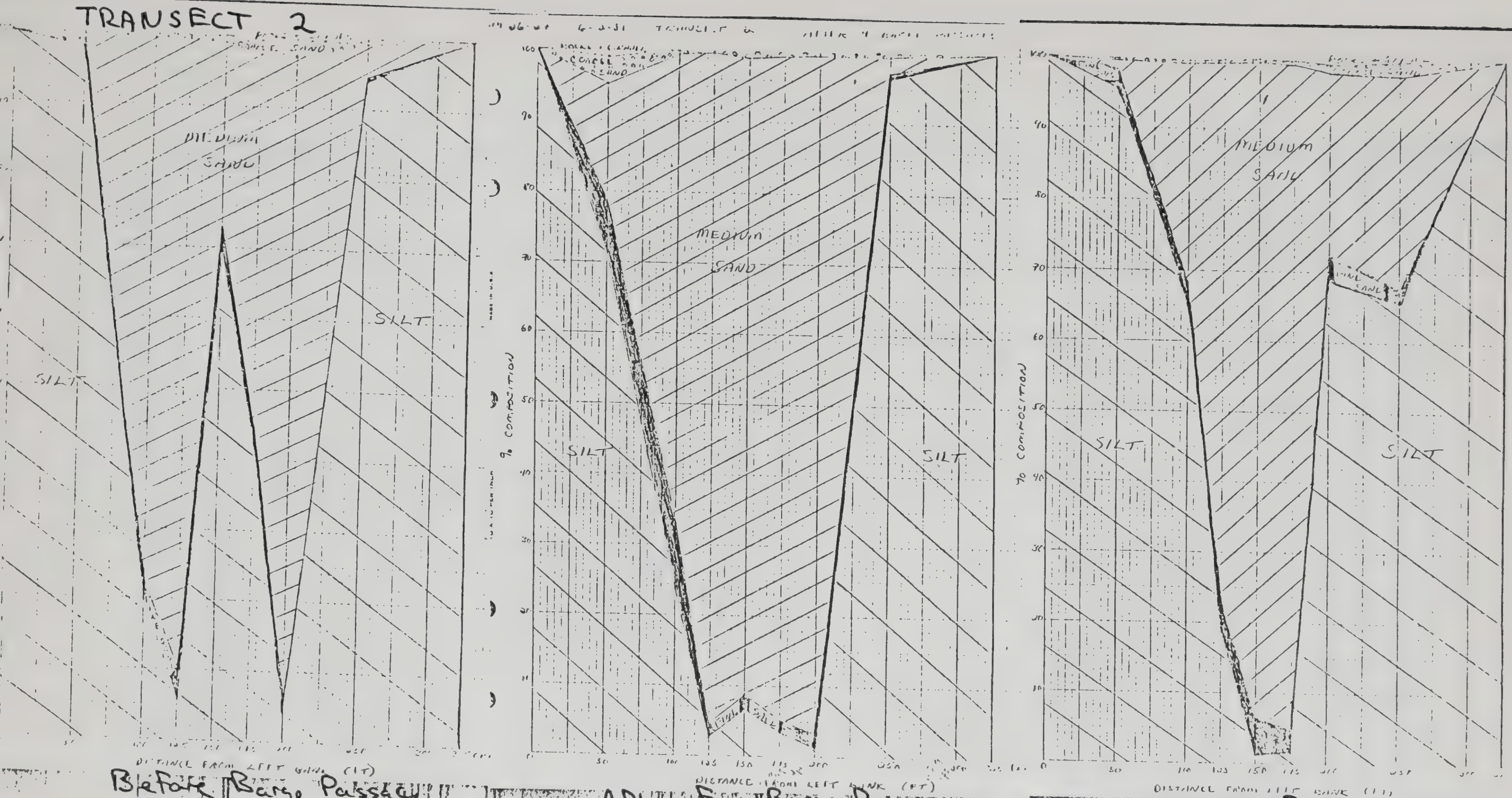


Before Passage

After 4 Passages

2 Weeks After BARGE Events

Figure 10

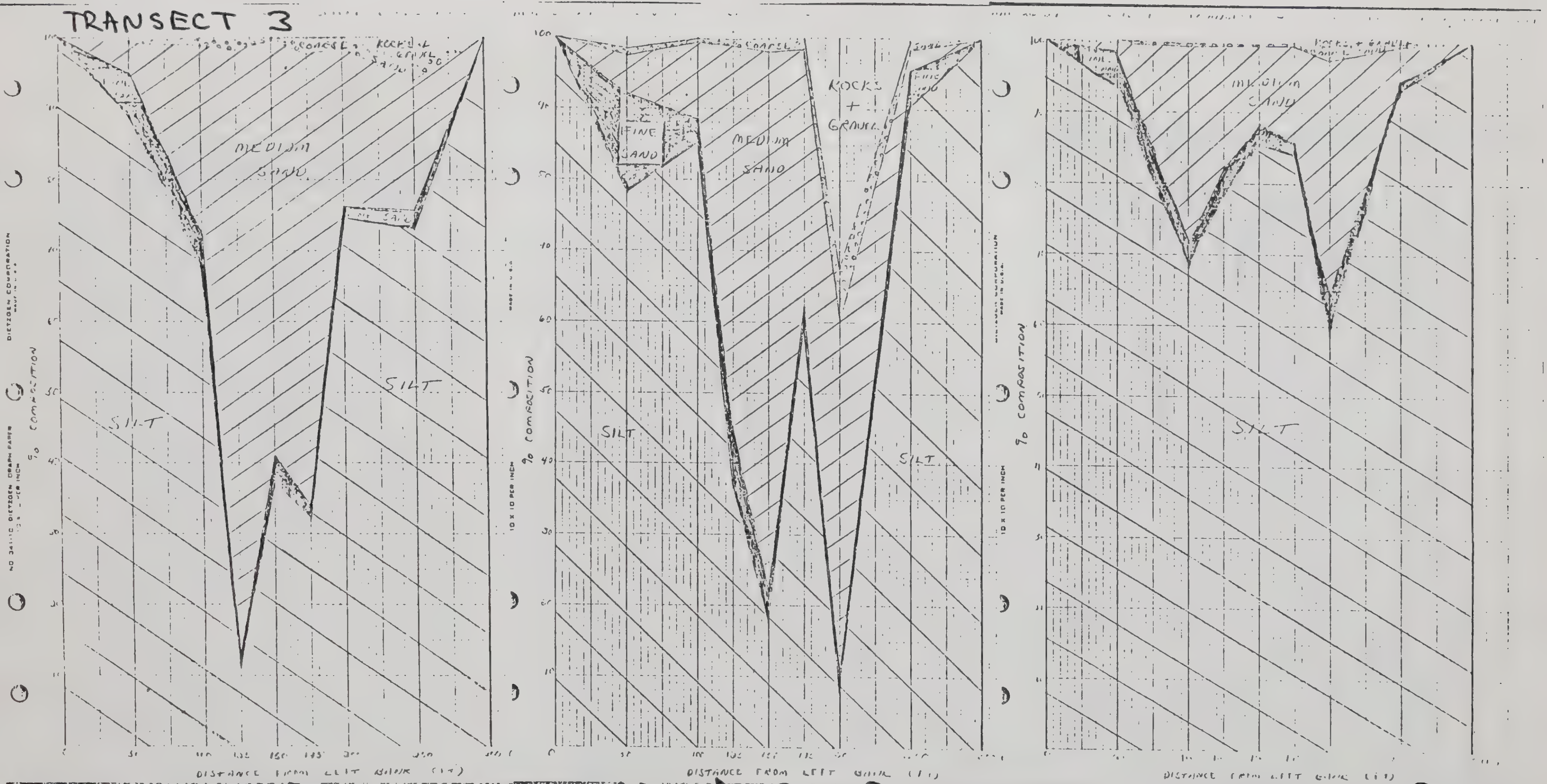


Before Barge Passage

After Four Barge Passages

2 Weeks After Barge Passage

Figure 11



Before

After four Barge Passages

2 weeks After Barge Passage

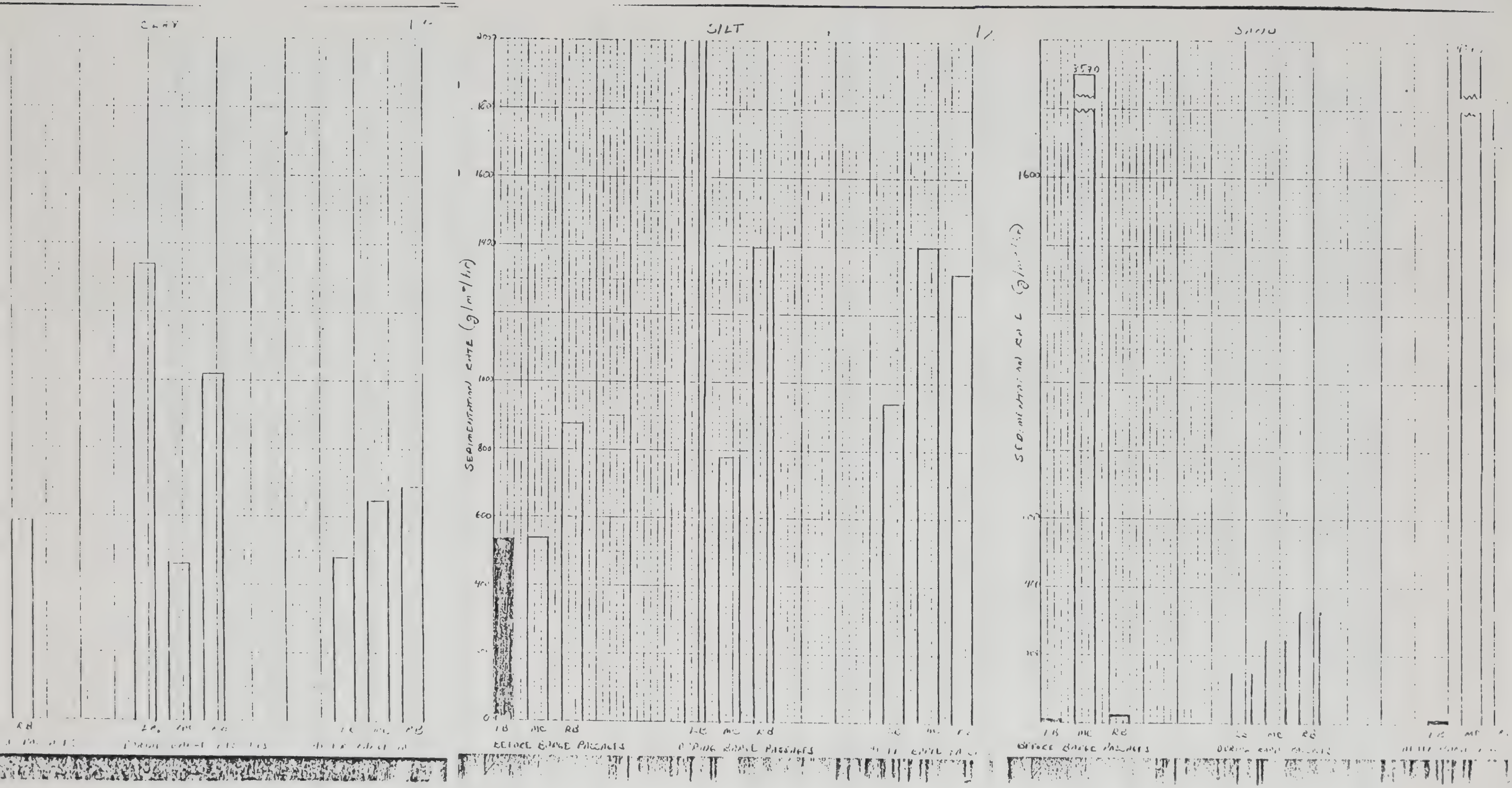

CLAY
SILT
SAND
SEDIMENTATION RATE (g/m²/hr)
0
400
600
800
1000
1400
1600
2000
3570
TB
MC
RB
BEFORE BARGE PASSAGES
DURING BARGE PASSAGES
AFTER BARGE PASSAGES

Figure 12

amount of sand in the sample significantly affects the weight proportions reported. Since such small amounts lead to major differences in estimated sedimentation rates, analysis error may have affected the results reported. A second explaination can be derived from observed sampling bias of the sediment traps. The trap consisted of four containers on a square concrete base. There were consistent differences between sets of samples (from the four replicates taken) based on location. The samples in the front (first to encounter the current) generally had reduced weights when compared with samples from the back of the block. The hydraulics of the sampling device have not been studied in detail, but it appears that more sediment is accumulated in rear containers because of an eddy effect. Slight variation in samples can account for a portion of the observed results, but additional explaination can be found when sediment characteristics are combined with known prop wash effects of a moving barge.

The observed differences in accumulation of sand during barge passage may be explained by the following mechanism. Due to repeated passage over the mid-channel location, sediment characteristics adjacent to the sediment traps was altered, and the traps themselves were affected by prop wash removing accumulated sediment during the passage events. Since only larger size fractions remained after the series of barge passages, there was no readily available source of sand to accumulate in the sediment traps. Even though background current velocities at high flow were capable of moving sand size material, only the lateral locations were not severely affected by prop wash. The result is the continued accumulation of sand after barge passage when sand had the time to move downstream from unaffected areas (sand bar movement has been observed but not quantified in 5 years of benthic organism studies on the Kaskaskia). The accumulation of clay and silt sized material in the traps during barge passage can be accounted for by accumulation rates similar to those observed before and after barge passage. Although this mechanism is supported by a review of the data on sediment characteristics it is impossible to verify the actual mechanism or base further speculation on a data base which is somewhat limited.

Chemical Results. The results of chemical analyses generally indicated changes similar to those observed during low flow studies, but the magnitude of change was attenuated by high flow conditions. Table 10 contains the temperatures recorded before and after barge passage. The water column was uniform in temperature along the bank, with some variability (a maximum of 2°C difference in the water column) noted in the main channel.

To assess the transparency before and after barge passage, Secchi disk readings were made observing the effects of the third and fourth passages of the day (Table 11). There appeared to be a slight decrease in transparency following barge passage with an improvement noted approximately 30 minutes following the final passage of the day.

Suspended solids analysis of samples collected before and after barge passage are contained in Table 12. In general, there was an increase in water column suspended solids following barge passage. This increase was somewhat delayed for samples collected lateral to the main channel, and very rapid for mid channel locations. The concentration of suspended solids in the water column was variable with time. The most pronounced effect at the lateral location occurred 15 to 30 minutes following barge passage, with the greatest increase 30 minutes following passage occurring in suspended load occurring at 2.5 m. Samples from the sailing line indicated

Table 10

Temperature Levels (°C) for a 6-2-81 Barge Passage

The first barge passage which traveled upstream and passed mile 26 transect #2 at 1039 was sampled 75 feet from the right bank of the canal.

depth	5BB	10AB
surf	24	24
1.0 m	24	24
2.0 m	24	24
3.0 m	24	24

The fourth barge passage which traveled downstream and passed mile 26 transect #2 at 1307 was sampled on the tow's sailing line

depth	10BB	5AB	30AB
surf	24	24	26
2 m	23	24	25
3 m	22	23	24

Table 11

Secchi Disc Readings (cm) for 6-2-81 Barge Passages. Two of Four Passages were Sampled.

The first barge passage at 1039 and the second barge passage at 1135 were not analyzed due to cloudy conditions.

The third barge passage which traveled upstream and passed mile 26 transect #2 at 1244 was sampled on the tow's sailing line.

event	time	Secchi depth (cm)
4BBU	1240	14
9ABU	1253	10
11ABU	1255	10
15ABU	1259	10
18ABU	1302	10

The fourth barge passage which traveled downstream and passed mile 26 transect #2 at 1307 was sampled on the tow's sailing line.

event	time	Secchi depth (cm)
5BBD	1302	10
3ABD	1310	9
10ABD	1317	11
18ABD	1325	11
31ABD	1338	13

Table 12

Suspended Solid Levels (mg/l) for 6-2-81 Barge Passages. Three of Four Passages were Sampled.

The first barge passage which traveled upstream and passed mile 26 transect #2 at 1039, was sampled 75 feet from the right bank of the canal. Depth ≈ 3.5 m.

depth	3AB	10AB	15AB	30AB
surf	286	295	345	290
1.5 m	251	341	326	321
2.5 m	285	294	289	333
Int. (g/m^2)	671	795	811	785

The second barge passage which traveled downstream and passed at 1135 was not sampled.

The third barge passage which traveled upstream and passed mile 26 transect #2 at 1244 was sampled on the tow's sailing line. Depth ≈ 4.5 m.

depth	4BB	10AB	20AB
surf	289	240	223
1.5	291	320	289
2.5	313	312	303
3.5	317	-	-
Int. (g/m^2) to 2-5 m only	737	736	680

The fourth barge passage which traveled downstream and passed mile 26 transect #2 at 1307 was sampled on the tow's sailing line. Depth ≈ 4.5 m.

depth	3BB	5AB	30AB
surf	223	294	185
1.5 m	289	284	371
2.5 m	303	300	496
3.5 m	-	315	-
Int. (g/m^2) down to 2-5 m only	680	732	850

generally greater suspended solids levels near the bottom; a delay was observed in reaching maximum integrated values when the barge traveled downstream. These results are similar to those obtained during low flow conditions, but there is an indication of differences in impact between upstream and downstream passage during high flow. With the upstream barge passage, a decrease in integrated suspended solids occurred during the 20 minutes following passage. On the downstream passage, integrated values continued to increase up to 30 minutes following passage.

Dissolved oxygen analysis indicated some decrease in integrated water column oxygen concentrations from samples along the bank, with slight increases in samples from the main channel (Table 13). The effect of upstream and downstream passage was again different. The upstream passage indicated a slight increase in dissolved oxygen, while the downstream passage indicated a slight decrease.

In reviewing the entire data set of chemical analyses, it is apparent that barge passage does change transparency, suspended solids and dissolved oxygen concentration. The changes noted are somewhat less than noted during low flow. There appears to be a delayed effect along the channel margins while main channel effects were almost immediate. The most significant difference was the effect of downstream and upstream passage. Although transparency increased following downstream passage, suspended solids concentrations, particularly at 2.5 m increased while dissolved oxygen decreased indicating a potential for different mechanisms of effect at low and high flow.

A brief discussion of the mechanisms which might explain the differences between downstream and upstream passage is warranted. During high flow,

Table 13

Dissolved Oxygen Concentrations (mg/l) for 6-2-81 Barge Passages. Three out of Four Passages were Sampled.

The first barge passage which traveled upstream and passed mile 26 transect #2 at 1039 was sampled 75 feet from the right bank of the canal. Depth ≈ 3.5 m.

depth	3AB	10AB	15AB	30AB
surf	7.36	7.24	7.14	7.19
1.5 m	7.39	7.14	6.83	6.88
2.5 m	7.41	6.93	7.04	6.88
Int. (g/m^2)	18.46	17.82	17.41	17.43

The second barge passage which traveled downstream and passed at 1135 was not sampled.

The third barge passage which traveled upstream and passed mile 26 transect #2 at 1244 was sampled on the tow's sailing line. Depth ≈ 4.5 m.

depth	4BB	10AB
surf	7.44	7.84
1.5 m	-	7.94
2.5 m	6.93	7.79
3.5 m	6.83	7.49
Int. 2.5	17.96	19.70
(g/m^2) 3.5	24.84	27.34

The fourth barge passage which traveled downstream and passed mile 26 transect #2 at 1307 was sampled on the tow's sailing line. Depth 74.5 m.

depth	3BB	5AB	30AB
surf	7.99	7.74	7.84
1.5 m	7.84	7.39	7.19
2.5 m	7.64	7.24	6.98
3.5 m	-	7.29	7.19
Int. 2.5	19.61	18.66	18.36
(g/m^2) 3.5	-	25.93	25.44

the tow moving upstream produces a scour vector which is coincident with the dominant velocity vector of current flow. With the combined velocity of the current and downstream scour, particles on the bottom would tend to move downstream faster than observed during low flow or if the barge is moving downstream. During downstream passage, the two still requires energy to overcome the resistance of the barges and a scour vector is directed opposite the prevailing current. The effect of opposing velocity vectors can be visualized as zones of material suspended in the water column causing additional disturbance (albeit minor) and assisting on the suspension of bottom materials in the water column. The continued rise in suspended solids observed in this study might also be accounted for by disturbance caused by tow manipulation upstream to facilitate the downstream passage. In the interval between upstream and downstream passage, the "Forward" changed position on the barges. Propwash and energy to start the tow moving in an upstream area would suspend bottom material locally. If an average current of 2 fps is assumed, the suspended materials would reach the experimental reach 30 to 45 minutes after the initial barge passage, corresponding approximately with the period of increased suspended solids concentrations. The data also indicates increased suspended solids concentrations with depth, a condition which might be expected if plug flow is assumed and settling occurs in the water column as it moves downstream. Again these mechanisms are supported mainly by speculation, but the observed results demand evaluation if for no other reason than to encourage further studies to verify or refute the proposed mechanisms.

Biological Results. The results of biological sampling include only analysis of drift collections. Ponar grab samples were collected and preliminary analysis performed, but analysis indicated no observable effect due to barge passage.

A total of 25 drift samples were collected associated with the June barge passages. Figure 11 shows the number of individuals collected per 10 minute tow. A high degree of variability was noted in the drift samples, with no extremely high peak noted following barge passage (as was the case in the March low flow study). Drifting organisms were dominated by chironomidae with other diptera the next most abundant group (Table 14). Mayflies made up a relatively small portion of the drifting organisms during the study. A review of the origin of drifting fauna, (Table 15), indicates the dominance of drifting organisms from the sides of the channel and relatively few from the bottom. This result is different from results obtained during low flow when bottom organisms dominated the drift immediately following barge passage.

It appears from these results that high flow conditions have altered drift patterns, and that barge passage effects are not as severe. The severity reduction can be related to the use of an unloaded tow as well as high background current which have maintained drift at high levels for some time prior to the June study. The most significant change appears in the origin of the drifting organisms. The consistency of side organisms dominating the samples, even following barge passage is apparent throughout the study.

Figure 11

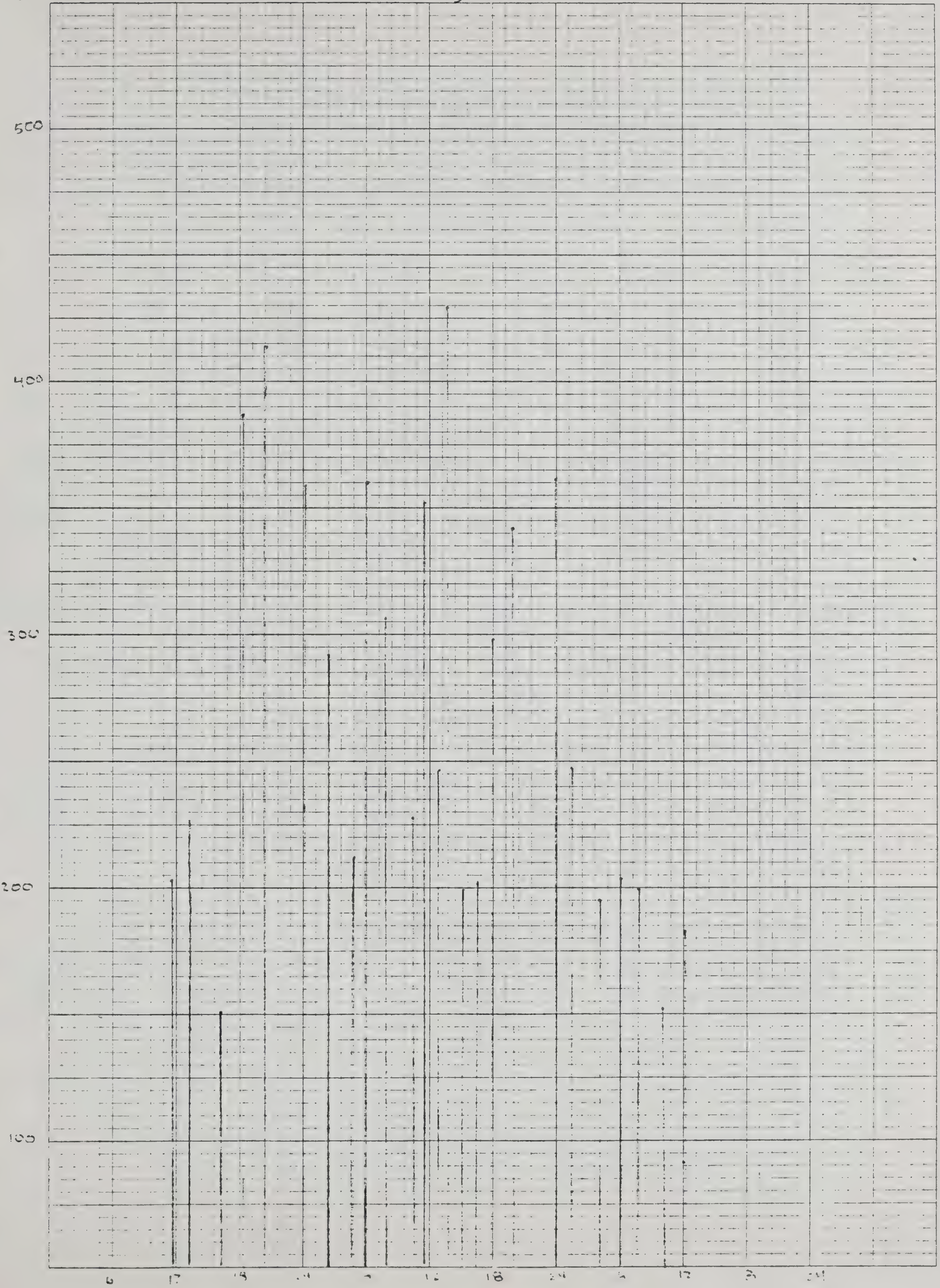


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Table 14

Total Number of Organisms per Taxonomic Groupings Collected in 10 Minute Drift Samples

	Time	I.D.	Ephemeroptera	Chironomidae	Other Diptera	Coleoptera	Odonata	Trichoptera	Plecoptera	Amphipoda	Hemiptera	Misc.	Total
6-1-81	11:29	20-24	1.5	156.25	45.25	1	0.25	0.5		0.75		1.75	207.5
	13:36	25-28	0.5	187.5	37.25	0.75	0.25	0.25				0.25	226.75
	16:12	29-32	0.25	127.25	21.25	0.25				0.25		1.5	150.75
	18:24	33-36	1.25	325.25	46.75	0.75	0.5	0.5		0.5		9.75	385.25
	20:12	37-40	3	347	60	0.5	0.25	0.75		0.5	0.25	1.25	413.5
6-2-81	00:17	41-44	3	272.75	81.25	1.5	0.5	0.25		0.25		0.25	359.75
	02:00	45-48	6.75	220	62.75	0.5	0.5	0.75				1	292.25
	04:31	49-52	6.25	156.25	46.75	0.75		1.75		0.25	0.25	0.5	212.75
	05:57	53-56	2	269.25	81	1.5	0.5	1	0.25	0.25	0.5	3.75	360
	08:05	57-60	3	238.75	59.75	2	0.25	0.5		0.25	0.25	1.75	306.5
	10:40	61-64	4.75	154.5	57.25	1.5	0.25	0.75				6.5	225.5
	11:38	65-68	3.5	272.5	71.75	1.75	0.25	0.5				1.75	352
	12:47	69-72	4	186	48.75	0.75	0.25	1.25	0.25	0.5	0.75	3.25	245.75
	13:14	73-76	5.5	345.75	69	0.75		2	0.25		1.75	3	428
	14:06	77-80	2	159	33.25	1	0.25	1		0.25		2.25	199
	16:07	81-84	1.5	148.75	50.5		0.5				0.25	0.25	201.75
	18:03	85-88	1.5	231	62.75	0.5		0.5			0.5	0.75	297.5
	19:57	89-92	3	253.25	80.5	1.25	0.25	0.5			1	2.25	342
	23:43	93-96	3	153.5	97.75	4		0.75			2.5		261.5
6-3-81	01:27	97-100	6.5	219	103.25	4.25	0.25	1		0.25	0.75	0.25	247.5
	04:08	101-104	5.5	94.5	81.5	8.5	0.25	2			2.5	0.25	195
	05:52	105-108	6.5	105.5	76	8	0.5	2.75	0.25	0.25	1.25	2.25	203.25
	07:54	109-112	4.75	133.5	55.75	1.5		1.5	0.25		1.5	0.75	199.5
	10:03	113-116	4.75	96	53	1.25					1		156
	12:02	117-120	3.5	122.5	53	1.25		2	0.25		0.25	0.75	183.5

Table 15

Percentage of Total Drift Sample with Fauna Typical of Bottom or Side Habitats.

Date	Time	ID	Side	Bottom	Misc
6-1-81	11:29	21-24	62.5	11.9	25.6
	13:36	25-28	80.3	3.7	16.0
	16:12	29-32	70.9	5.7	23.4
	18:24	33-36	77.3	3.6	19.1
	20:12	37-40	67.1	4.5	28.4
6-2-81	00:17	41-44	54.8	9.7	35.5
	2:00	45-48	78.1	4.9	17.0
	4:31	49-52	74.1	9.2	16.7
	5:57	53-56	80.1	3.6	16.3
	8:05	57-60	67.6	5.9	26.5
	10:40	61-64	72.8	3.7	23.5
	11:38	65-68	74.8	5.3	19.9
	12:47	69-72	59.1	11.2	29.7
	13:14	73-76	75.1	7.1	17.8
	14:06	77-80	48.2	16.1	35.7
	16:07	81-84	70.2	6.4	23.4
	18:03	85-88	50.3	11.0	38.7
	19:57	89-92	66.3	7.6	26.1
	23:43	93-96	47.2	12.1	40.7
6-3-81	1:27	97-100	30.9	20.0	49.1
	4:08	101-104	31.7	15.2	53.1
	5:52	105-108	35.2	7.4	57.4
	7:54	109-112	36.8	15.9	47.3
	10:03	113-116	29.2	20.4	50.4
	12:02	117-120	36.3	22.4	41.3

General Summary. It is possible to provide a general summary of the results of both low flow and high flow studies, comparing and contrasting results and reviewing proposed mechanisms which would explain the results.

The major effects of barge passage on physical conditions during both low and high flow include modification of bottom substrates, and increases in suspended solids. During high flow, a decrease in water column transparency was observed and minor modification of temperature profiles was recorded. The modification of bottom materials indicated by size class analysis varied between transects and showed little lasting impact as soon as two weeks following passage over bottom materials normally not subjected to barge passage. In general there was a short term effect which included an increase in larger size fractions, due most likely to scouring effects of barge passage. During high flow, main channel substrates had noticeable amounts of coarse sand, rocks and gravel which may have been produced by a combination of propwash and observed high velocities due to high discharge during the period of the study.

Suspended solids background concentrations were lower during low flow conditions than those observed during high flow. During low flow conditions, the passage of the first barge more than doubled suspended solids concentrations in mid channel (integrated for the water column) while passage high flow increases averaged less than 10% of background levels. The low flow results indicated a movement of sediment along the bottom following barge passage. High flow results indicated a similar pattern of movement. During low flow, a relatively rapid decay of suspended solids concentration occurred. During high flow, a similar decay was observed during upstream passage, but suspended solids concentrations continued to rise for 30 minutes following passage.

The mechanisms proposed to explain the results observed find support in data, but can not be considered conclusive without further detailed analysis, including replication of flow conditions and tow characteristics including experimental manipulation of the variables involved.

Additional analyses for dissolved oxygen and chlorophyl for one or both studies indicated some modification of concentrations typical of results identified in previous studies (Herricks and Gantzer, 1980). Dissolved oxygen typically showed some decline in water column integrated values. Chlorophyl concentrations showed some uniformity following barge passage indicating mixing of the water column. There were some differences between low flow and high flow. In particular, upstream passage during high flow resulted in a slight increase in dissolved oxygen concentration while downstream passage resulted in a slight decrease in concentration. There was little change in temperature profiles observed during the high flow studies.

The effects of barge passage on bottom fauna was mixed. Although during low flow the numbers of drifting organisms increased significantly following barge passage, the change in the bottom fauna community was insignificant as observed in ponar sample analysis. To review the changes in drifting organisms observed during both low flow and high flow studies, further analysis has been performed. Table 16 provides a key to all the samples collected as a part of low flow (March) and high flow (June) studies. ANOVA and the Duncan's multiple range *a posteriori* tests were applied to the drift data, tables 17 through 20. The results of these analyses can be summarized as follows:

1) Based on the sampling performed, there appears to be only a slight increase in the number of drifting organisms

Table 16

Times Drift Samples were Collected and Dates in the Kaskaskia River and the Group Code for each Time Period. *Designates Samples were Collected Immediately Following the Passage of a Barge.

Date	Time	Group (GP)	Number of Replicates
Mar 15	6:11	1	2
	12:24	2	2
	19:26	3	2
Mar 16	14:50	4	2
	15:45*	5	2
	16:55*	6	2
Mar 17	7:00	7	2
	12:30	8	2
	18:00	9	2
	23:30	10	2
June 1	11:29	11	4
	13:36	12	4
	16:12	13	4
	18:24	14	4
	20:12	15	4
June 2	0:17	16	4
	2:00	17	4
	4:31	18	4
	5:57	19	4
	8:05	20	4
	10:40*	21	4
	11:38*	22	4
	12:47*	23	4
	13:14*	24	4
	14:06	25	4
	16:07	26	4
	18:03	27	4
	19:57	28	4
	23:43	29	4
June 3	1:27	30	4
	4:08	31	4
	5:52	32	4
	7:54	33	4
	10:03	34	4
	12:02	35	4

Table 17

Results of oneway ANOVA on the total number of individuals collected from the drift in the Kaskaskia River analyzed with respect to day and time of sampling, and the associated *a posteriori* comparisons. N.S.= not significant at $p < 0.05$; * indicates period immediately following barge passage. See Table 1 for corresponding group (6P) time period. Underlines indicate members of a subset not significantly different.

Comparison - Date	ANOVA Results	Duncan's *a posteriori* Test Results
No. Ind. x Time (Mar 15)	N.S.	N.S.
No. Ind. x Time (Mar 16)	$p < 0.016$	$\text{GP4} < \underline{\text{GP6 GP5}}$
No. Ind. x Time (Mar 17)	$p < 0.020$	$\underline{\text{GP9 GP8 }\underline{\text{GP7}}}\underline{\text{ GP10}}$
No. Ind. x Time (June 1)	$p < 0.001$	$\underline{\text{GP 13 GP11 GP12}}\ \underline{\text{GP14 GP15}}$
No. Ind. x Time (June 2)	N.S.	N.S.
No. Ind. x Time (June 3)	N.S.	N.S.

Table 18

Results of *a posteriori* comparisons of the total numbers of individuals collected in the drift for each time period throughout the study. * indicates period immediately following barge passage. See Table 1 for corresponding date and time period for each group (GP). → indicates groups up to and including the group from previous subset.[a]

SUBSET 1	GP9, GP8, GP4, GP2, GP1, GP7, GP3, GP10, GP34, GP31, GP13, GP32, GP35, GP26, GP33, GP30
SUBSET 2	GP1 → GP30, GP11, GP25, GP29, GP18, GP21
SUBSET 3	GP10 → GP21*, GP12, GP23
SUBSET 4	GP31 → GP23*, GP17, GP27
SUBSET 5	GP13 → GP27, GP20
SUBSET 6	GP33 → GP20, GP28
SUBSET 7	GP11 → GP28, GP19, GP16, GP22*
SUBSET 8	GP17 → GP22*, GP14, GP15, GP24*, GP6*, GP5*

[a] Note - If a group occurs in the same subset as another group the two groups are not significantly different ($p < 0.05$), if they are not contained in the same subset they are signficantly different.

Table 19

Results of a posteriori comparisons of all sampling times for the total number of individuals of bottom indicator taxa collected from the drift throughout the study. * indicates time period immediately following barge passage. See Table 1 for corresponding date and time period for each group (GP). → indicates groups up to and including group from previous subset.

SUBSET 1	GP2, GP9, GP8, GP1, GP4, GP21*, GP12, GP13, GP26, GP7, GP19, GP17, GP32, GP14, GP18, GP22*, GP15, GP20, GP31, GP29, GP11, GP23*, GP16, GP28, GP33, GP3, GP34, GP24*, GP35, GP25, GP27
SUBSET 2	GP1 → GP27, GP30
SUBSET 3	GP4 → GP30, GP10
SUBSET 4	GP6, GP5

Table 20

Results of *a posteriori* comparisons of all sampling times and total numbers of individuals of side indicator taxa collected in the drift throughout the study. * indicates time periods immediately following barge passage. See Table 1 for corresponding date and time period for each group (GP). → indicates groups up to and including group from previous subset.

SUBSET 1	GP8, GP9, GP7, GP4, GP2, GP3, GP10, GP5*, GP1, GP6*, GP34, GP31, GP32, GP30, GP35, GP33, GP25, GP29, GP26, GP13, GP27, GP11, GP23*, GP21*
SUBSET 2	GP4 → GP21*, GP18
SUBSET 3	GP35 → GP18, GP12
SUBSET 4	GP25 → GP12, GP20, GP16, GP28, GP17
SUBSET 5	GP23 → GP17, GP22*
SUBSET 6	GP12 → GP22*, GP19, GP15
SUBSET 7	GP28 → GP15, GP14, GP24*

between the hours of 1800 and 2400, Table 17.

2) Correlated with barge passage during high flow, significantly greater numbers of organisms were encountered in the drift during the low flow passage. Barge passage significantly increased the number of drifting organisms in March.
3) There was no significant difference in the number of organisms in the drift during high flow barge passage despite 4 passage events.
4) Over the entire study, the highest number of organisms occurred in the drift in samples collected following barge passage in the March low flow period, Table 18.
5) Even though high numbers were found in March, low flow samples, equally high numbers were found in 9 other samples, two were associated with high flow barge passage. The greatest numbers of drifting organisms collected during the high flow studies were associated with downstream passage, Table 18.
6) A significantly greater number of organisms typical of bottom habitats occurred immediately following barge passage during the low flow studies than were recorded before passage, Table 19.
7) During the high flow studies, analysis indicates no significant difference in the numbers of organisms typical of bottom habitats collected during barge passage although there was an increase in the number of organisms typical of side or lateral habitats observed following downstream passage.
8) The number of organisms typical of side habitats observed in March was significantly less than 10 other samples. All of

these samples occurred in June. The number of organisms typical of side habitats during the two downstream passages were significantly higher than 28 of the 34 other samples including the upstream passages occurring immediately before these samples, Table 20.

In summary, there is variability in drifting organisms. The apparent differences in origin of drifting organisms during high flow is of particular interest. It is likely that during low flow bottom organisms remain relatively undisturbed unless scoured by barge passage. During high flow scour naturally occurs. Taken as part of background, this natural scour will affect bottom habitat dwellers more than side habitat dwellers because of the greater protection and morphological adaptions (hooks, claws, etc.) typical of side habitat fauna. During barge passage during high flow conditions few bottom organisms would be entrained while organisms typical of side habitats would be the major source of drifting organisms. The effects of wave wash or some other mechanisms associated with barge passage could add a disturbance in addition to prevailing high flow conditions to initiate drift. The interesting result is that drift initiation coincided with downstream passage. It is possible that the disturbance or propwash opposite current may create enough disturbance to initiate drift or the manipulation of the tow upstream caused propwash to be directed to the bank initiating drift upstream which was carried through the experimental reach.

CONCLUSIONS

The following conclusions are supported by data collected as a part of these studies. The mechanisms which produced the effects observed are not clearly understood and require further, and more detailed study to arrive at actual mechanisms.

1) Barge passage alters substrate conditions in a reach where passage normally does not occur. There was variable effect observed across different transects and conditions similar to prepassage conditions were restored in as little as two weeks.
2) Barge passage increases suspended solids concentrations with the greatest increase occurring during low flow conditions. There were differences observed between main channel and lateral locations, the main channel locations were affected immediately, a delay of up to 30 minutes was observed at lateral locations.
3) Temperature was little affected by barge passage during high flow. Chlorophyl concentrations were relatively uniform through the water column following barge passage during low flow. Dissolved oxygen concentrations generally decreased following barge passage although some variability was noted in high flow downstream passage concentrations.
4) Benthic communities, as indicated by ponar grab sampling, showed no significant change following barge passage during low flow.
5) Drifting organisms were significantly increased following barge passage during low flow. The organisms in the drift following low flow barge passage were typical of main channel habitats.
6) No significant increase in the numbers of drifting organisms were observed during high flow studies. Significant differences were noted in the origin of drifting organisms. Drift during

high flow originated from lateral or side channel habitats. Significantly greater rates of drift were observed from side organisms following downstream passage during high flow.

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